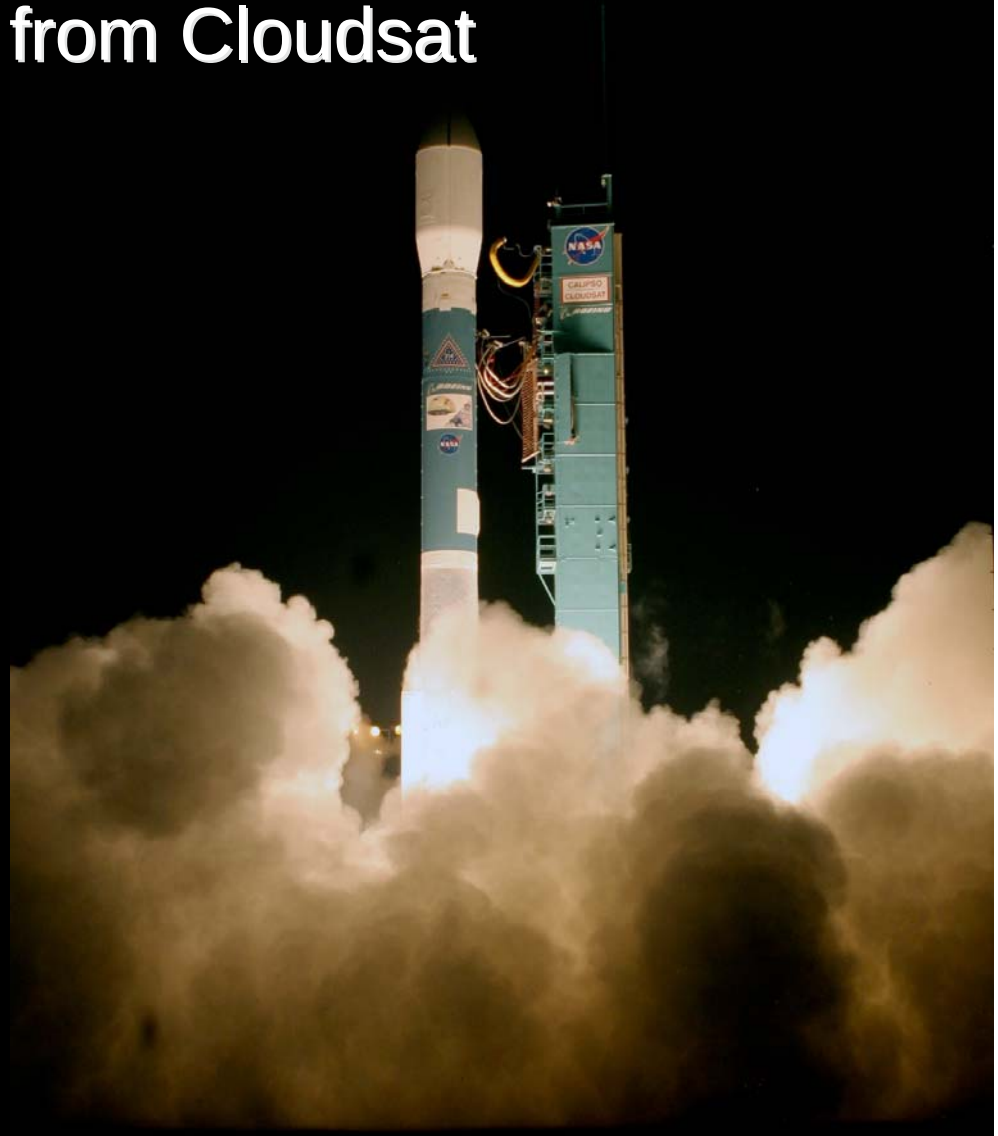
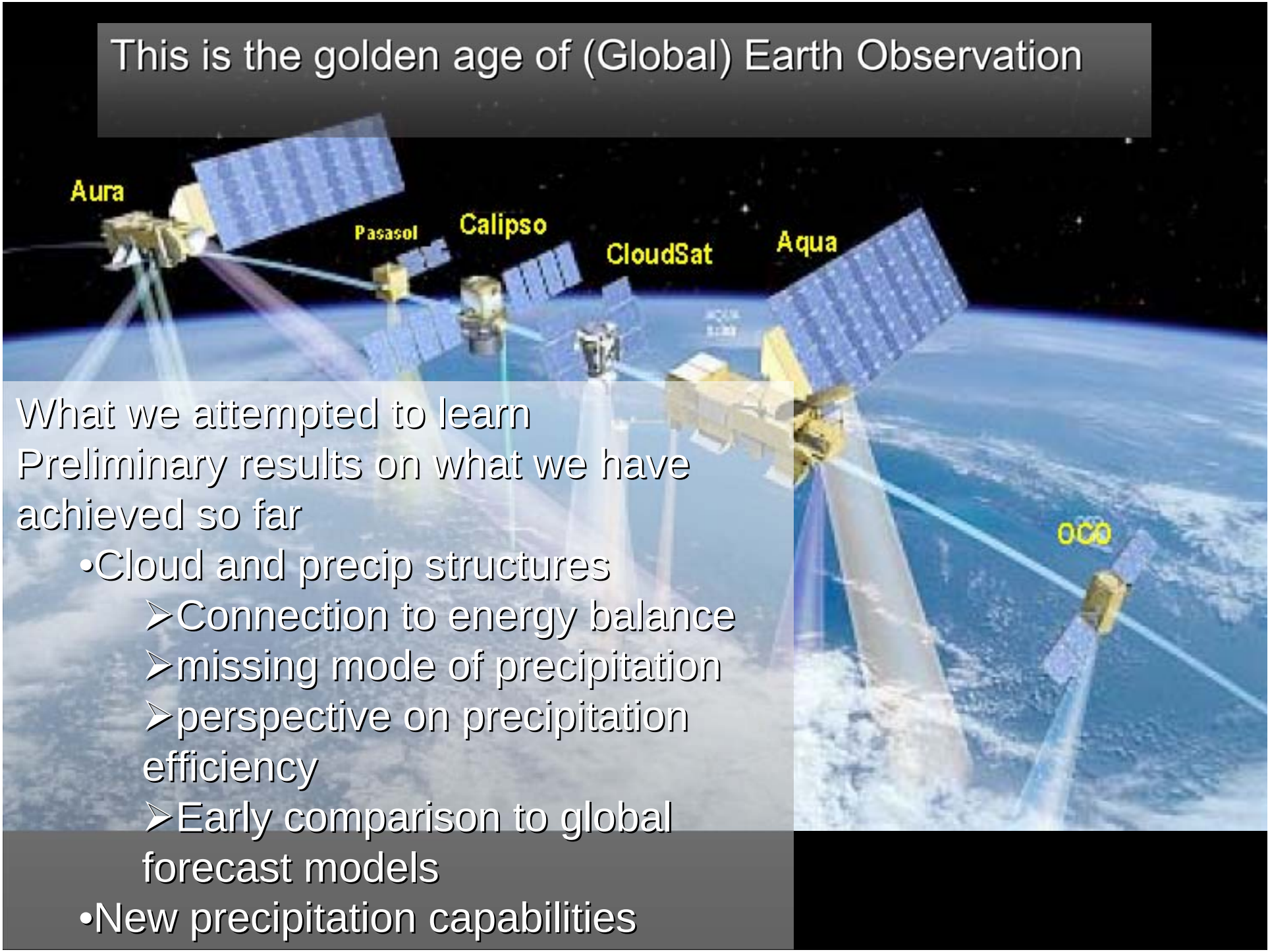
New insights on the hydrological cycle of Earth: Early results from Cloudsat

Graeme Stephens

- **CloudSat successfully launched April 28, 2006**
- **Operationally collected data since June, 2 (>98% all data since has been processed)**
- **Products released at end of January**
- **2year funded mission, seeking an extension for further 3 years**



This is the golden age of (Global) Earth Observation



What we attempted to learn
Preliminary results on what we have achieved so far

- Cloud and precip structures
  - Connection to energy balance
  - missing mode of precipitation
  - perspective on precipitation efficiency
  - Early comparison to global forecast models
- New precipitation capabilities

CloudSat Mission science goals

•*Measure vertical structure of clouds, quantify their ice and water contents as a step toward improved weather prediction and understanding of clim*

What are the fu

How do structure &

What f

What is the r

•*Quantify the relations heating by clouds*

Do clouds heat or cool the atmosphere (relative to clear skies)?

Do the radiative properties of precipitation and non-precipitating clouds differ?

•*Evaluate cloud information derived from other research and operational satellites*

•*Improve our understanding of aerosol indirect effect on clouds and precipitation*

To what extent are the properties above (water, ice, precipitation, vertical structure) influenced by aerosol?

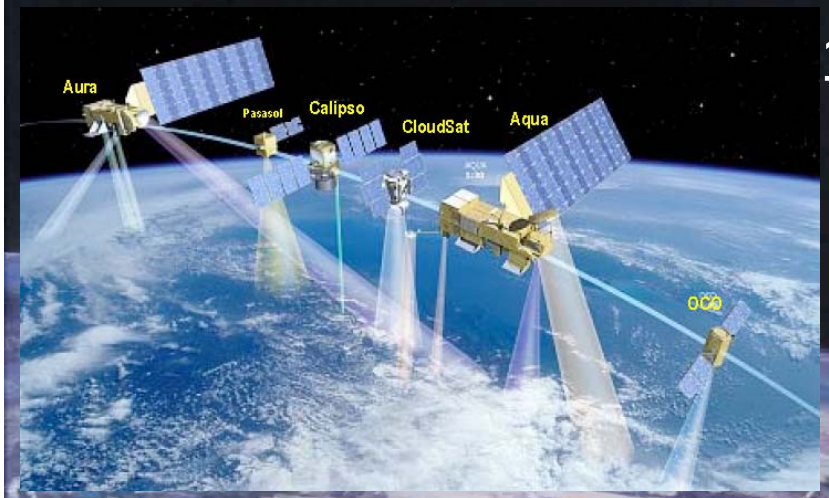
•Products

• various cloud properties - profiles, cloud physics, etc T,q analysis

•Precipitation incidence

•Quantitative precipitation

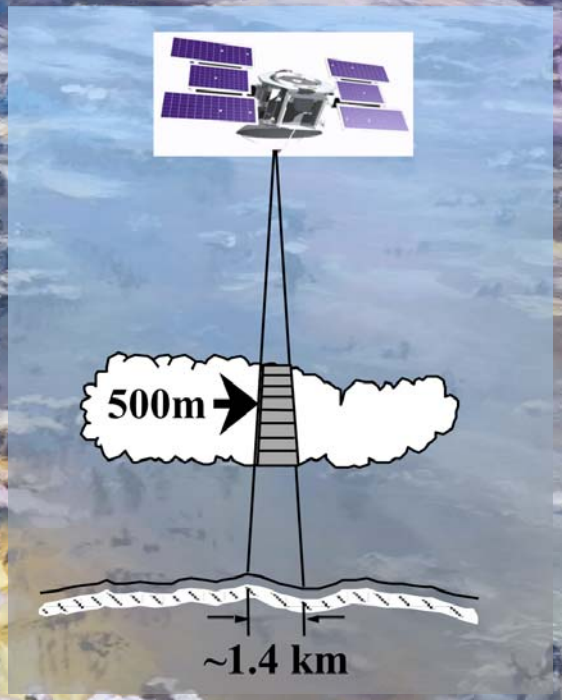
Two components to the mission design



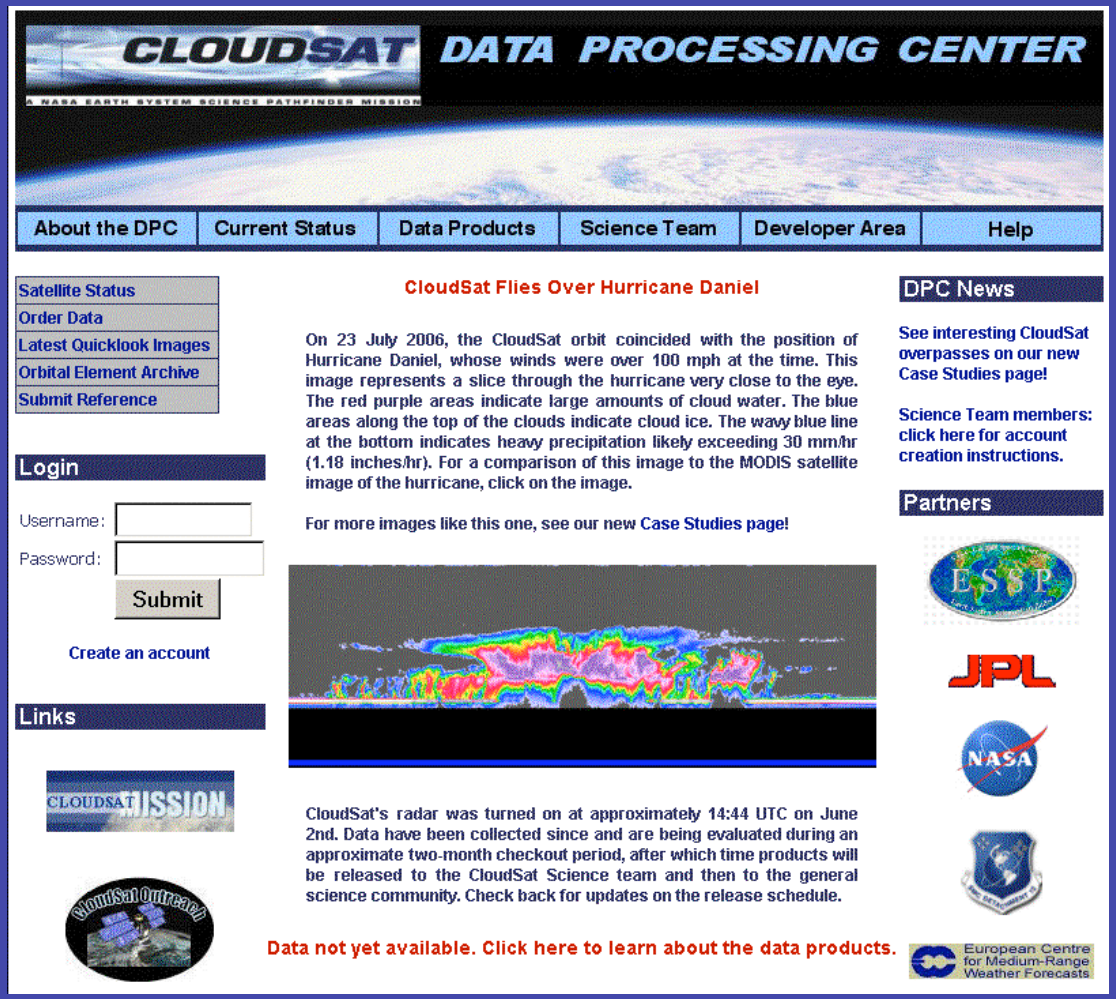
1. Formation with the A-Train

2. The Cloud Profiling Radar (CPR)

- Nadir pointing, 94 GHz radar
- 3.3μs pulse ➔ 480m vertical res, over- sampled at ~240m
- 1.4 km horizontal res.
- Sensitivity ~ -28 dBZ (-31 dBZ)
- Dynamic Range: 80 dB



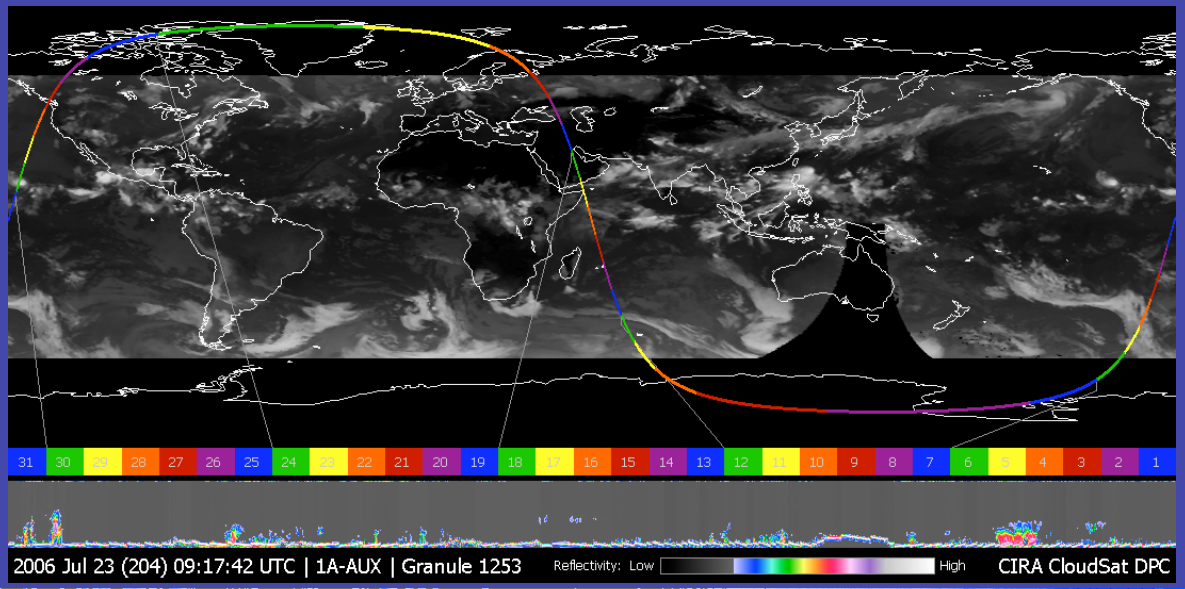
CloudSat Data Processing Center (DPC)

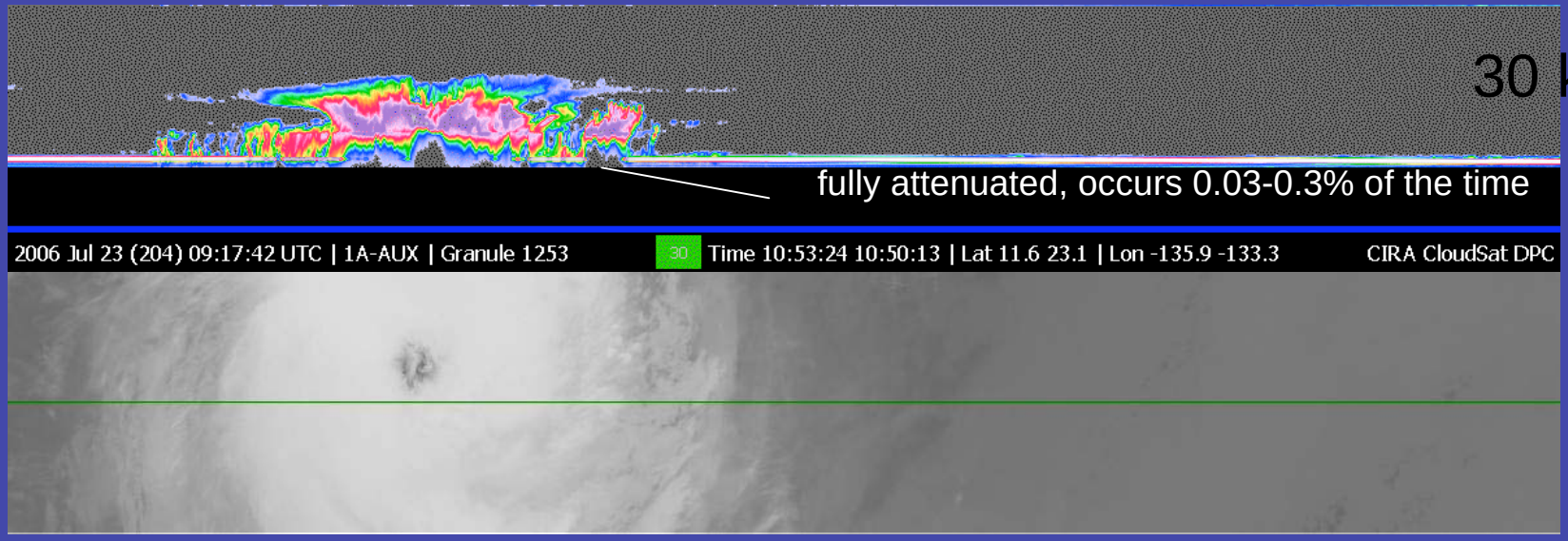


http://www.cloudsat.cira.colostate.edu

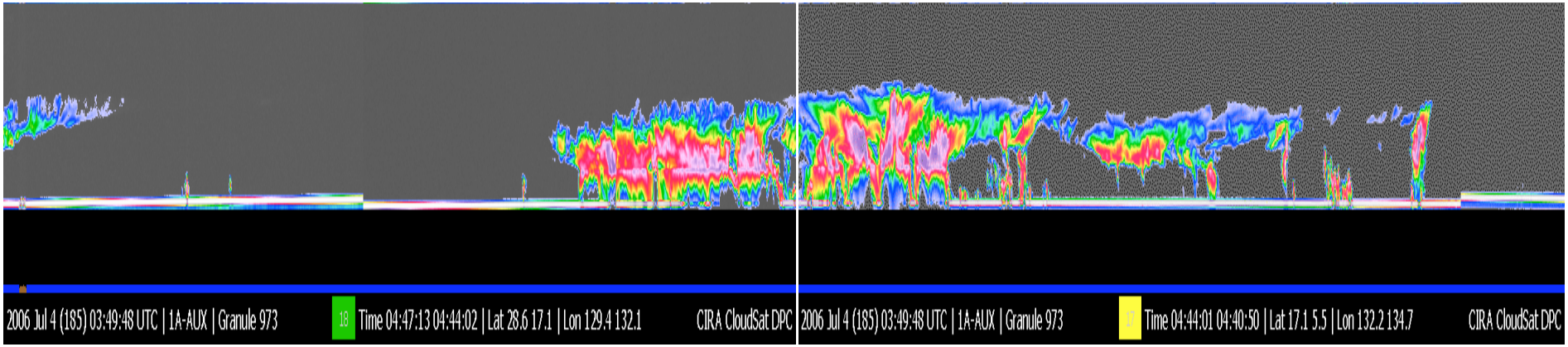
also Stephens et al, 2002; BAMS

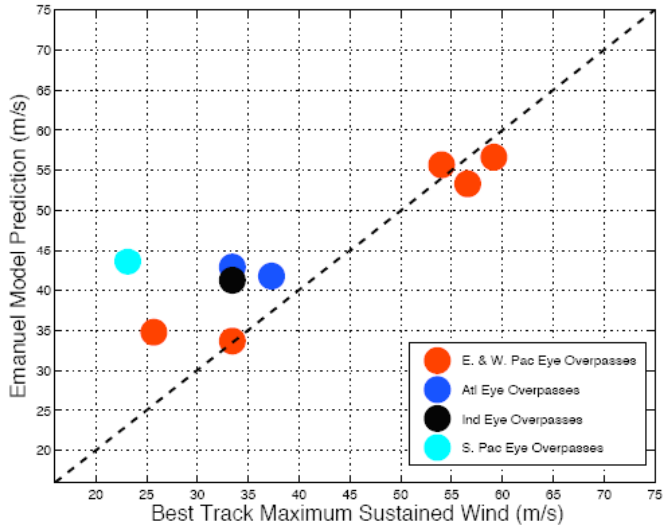
CloudSat – Quicklook Image - Geo and MODIS imagery

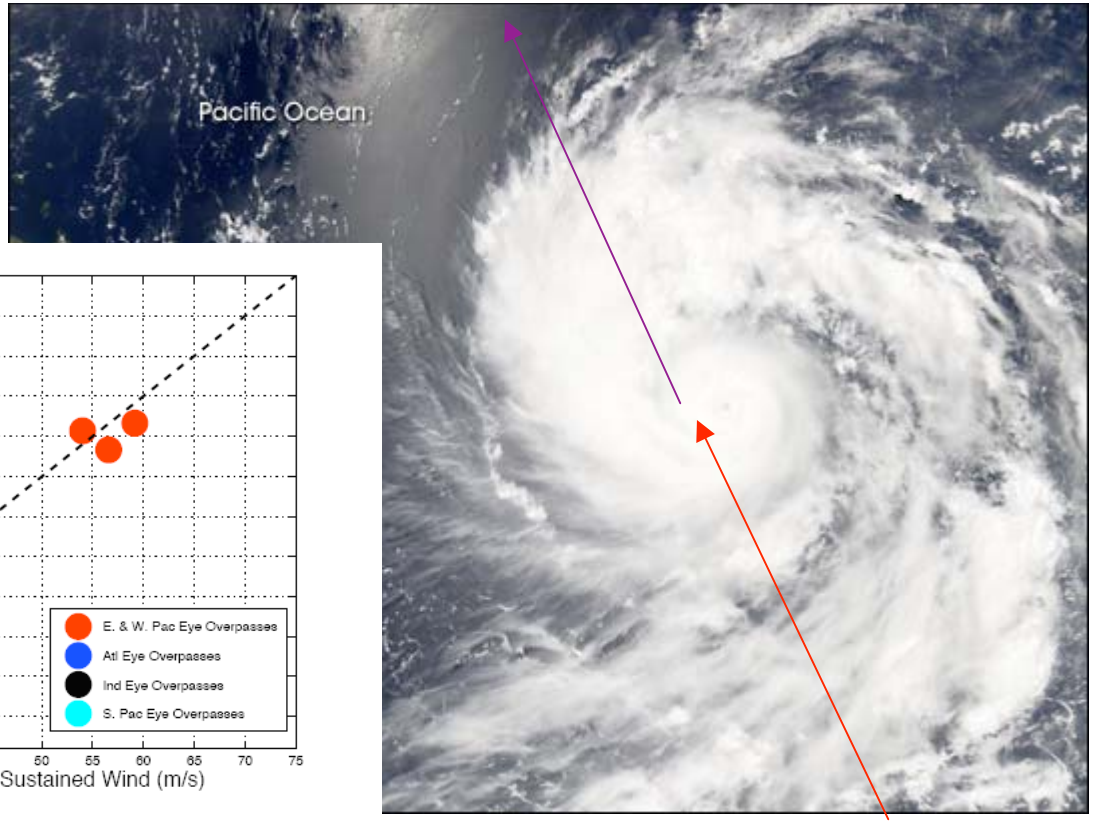




1400 km



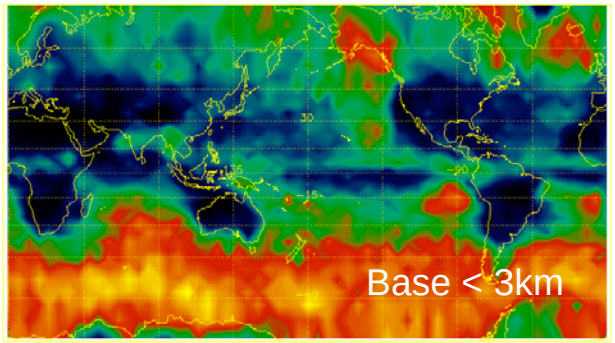


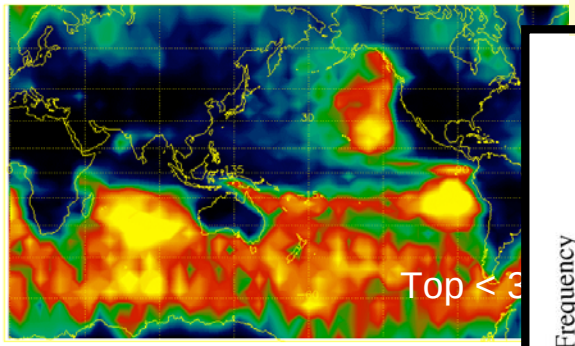


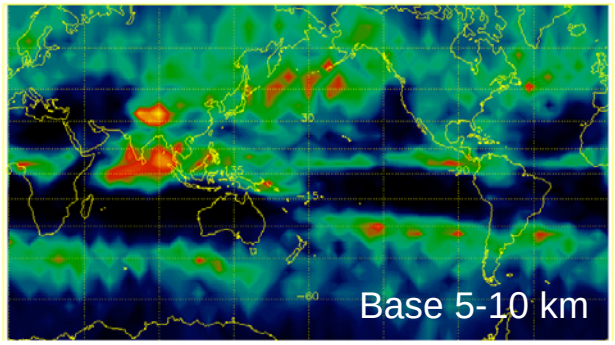
Day 185 July 4
20,130

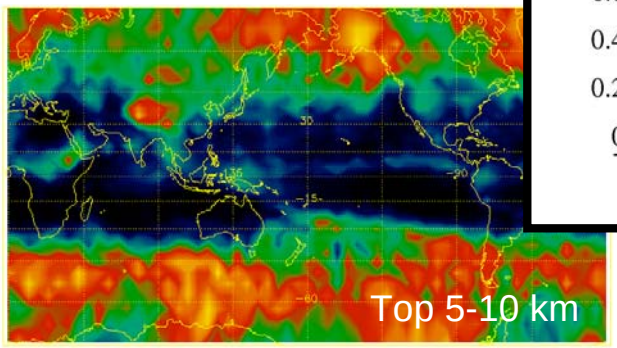
Through the Eye of Typhoon Ewiniar

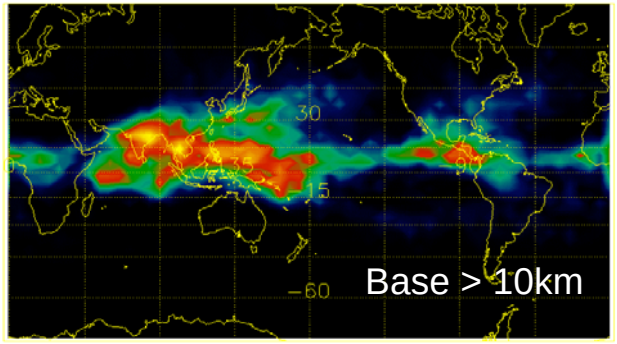
Example of cloud structure statistics (JJA)
- *2B geoprof*

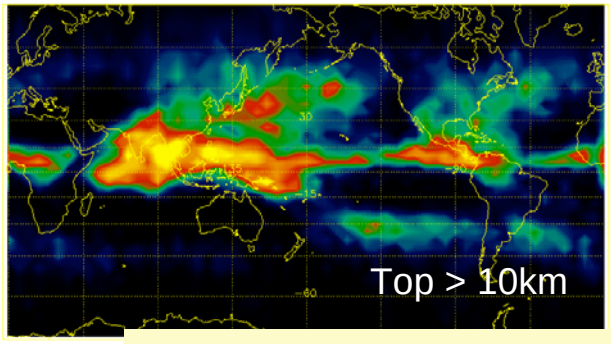




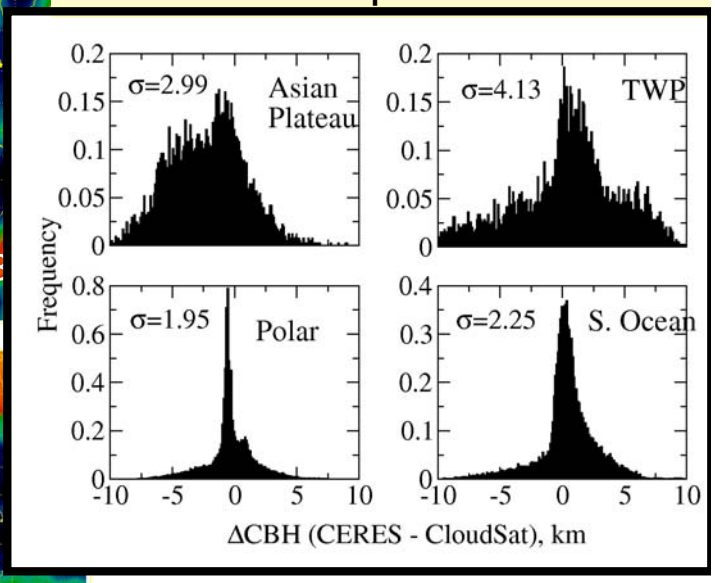








Cloud base differences from other satellite products

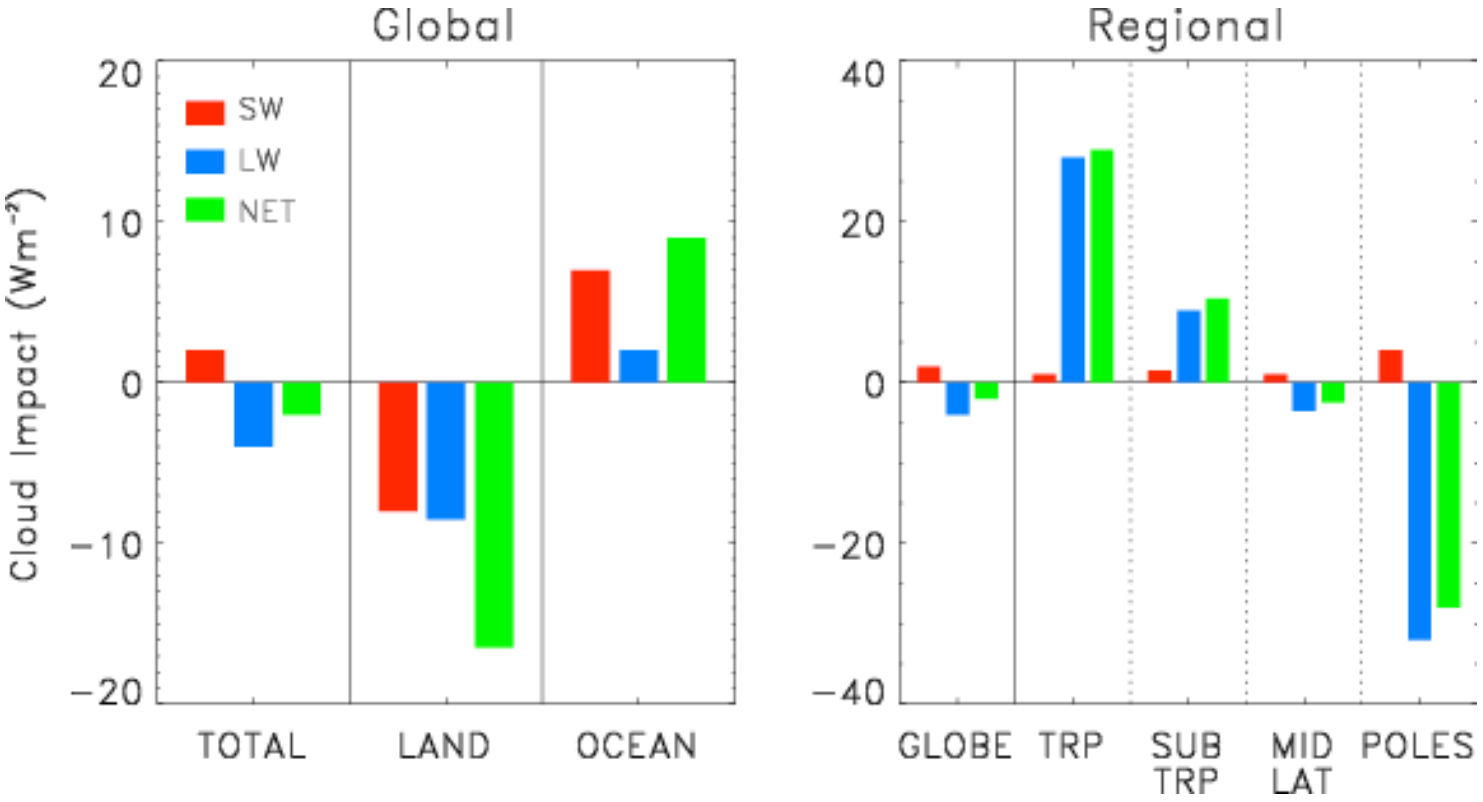


rms differences 2-4 km
500m ~ 5-10 Wm^{-2}

Mace et al, 2007

Cloud ‘Impact’ on Radiative heating of atmosphere

2b-fluxhr product

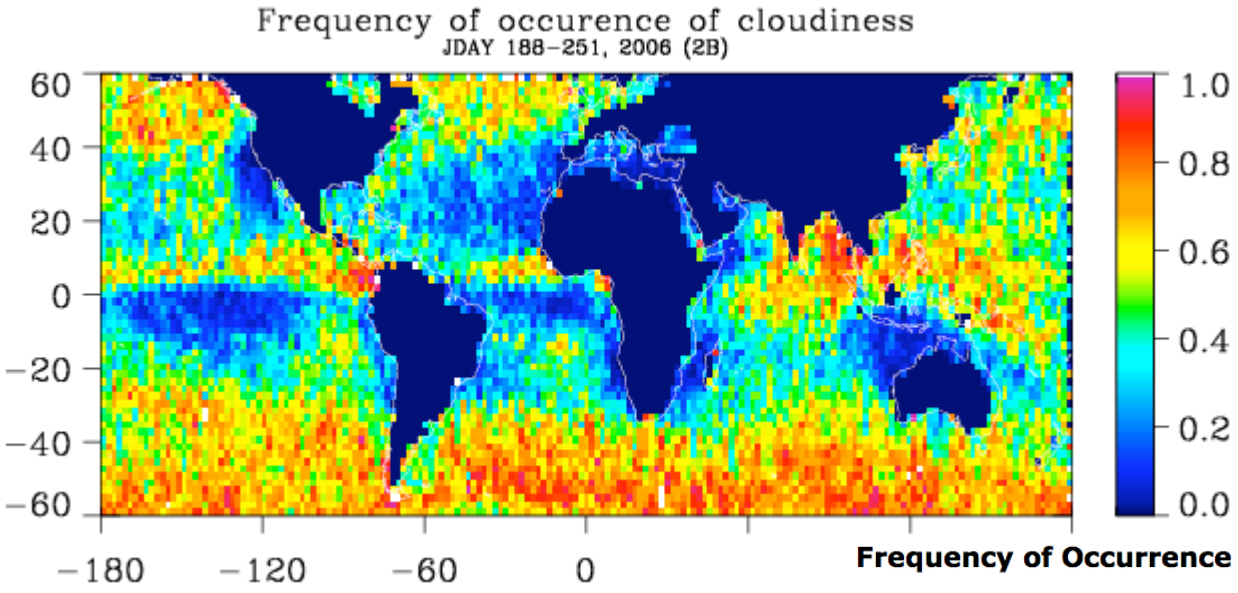


Preliminary, one month of data

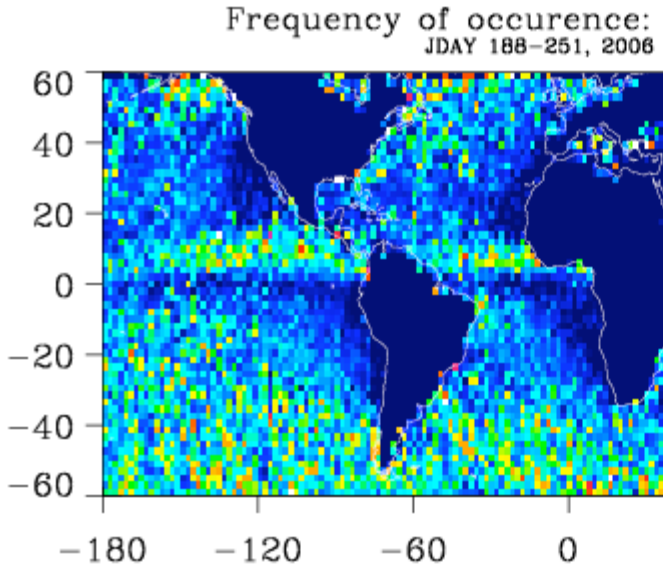
Clouds over global land areas radiatively cool

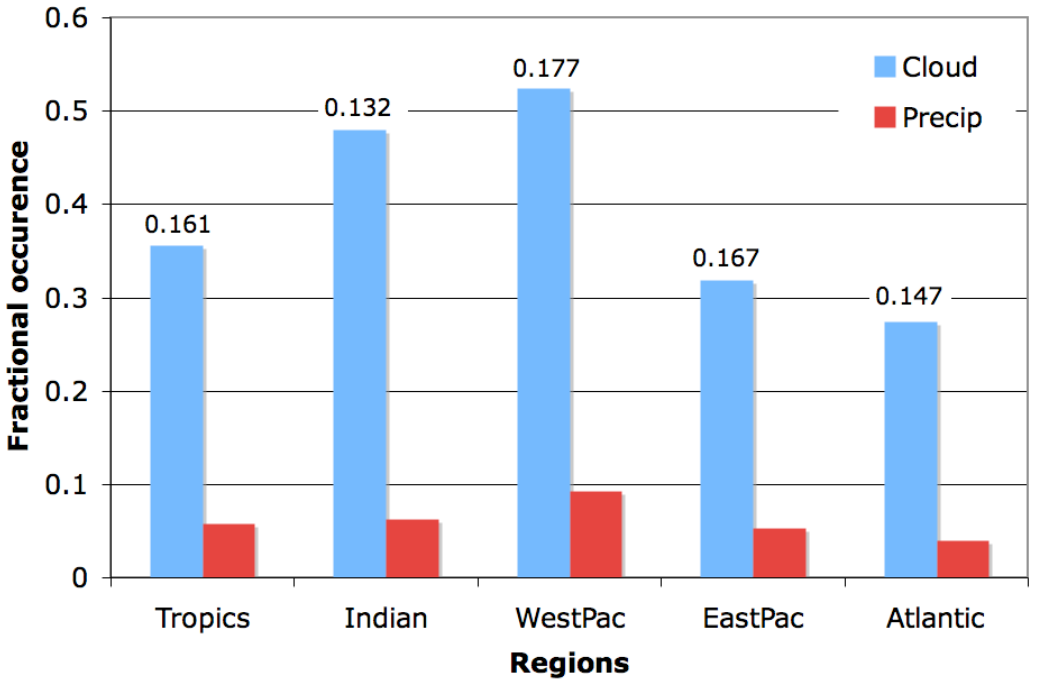
Clouds over global oceans radiatively heat

?????

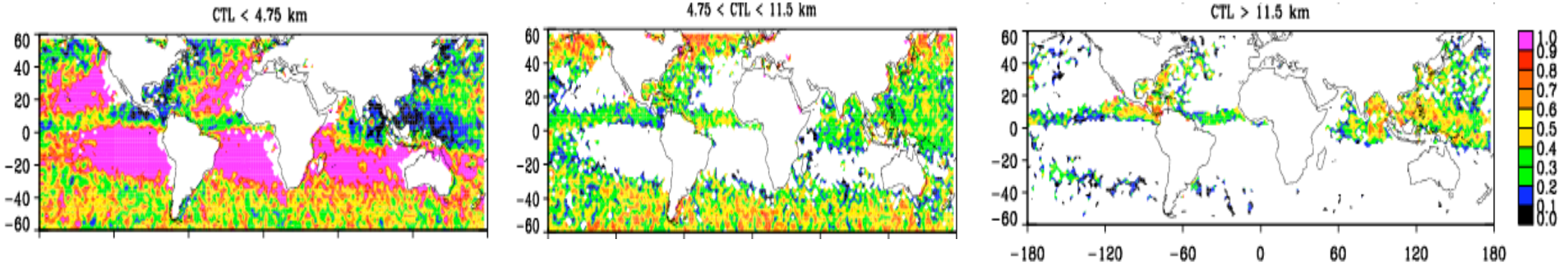


Frequency of Occurrence of Clouds and Precipitation

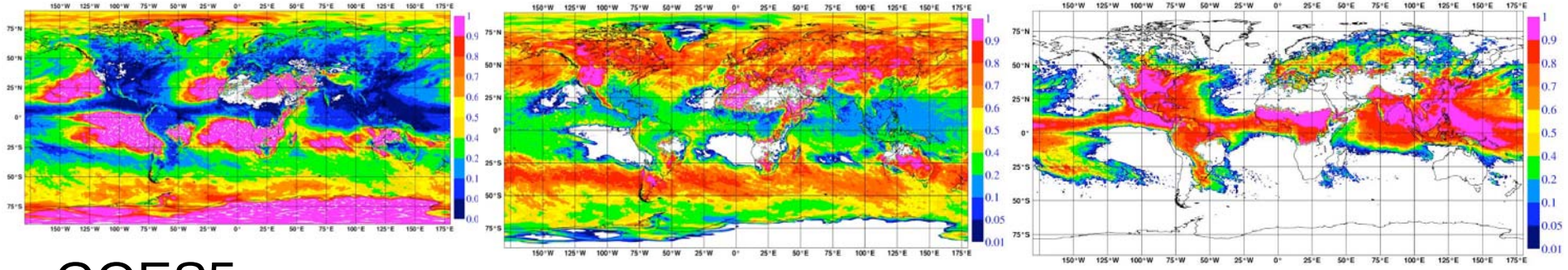




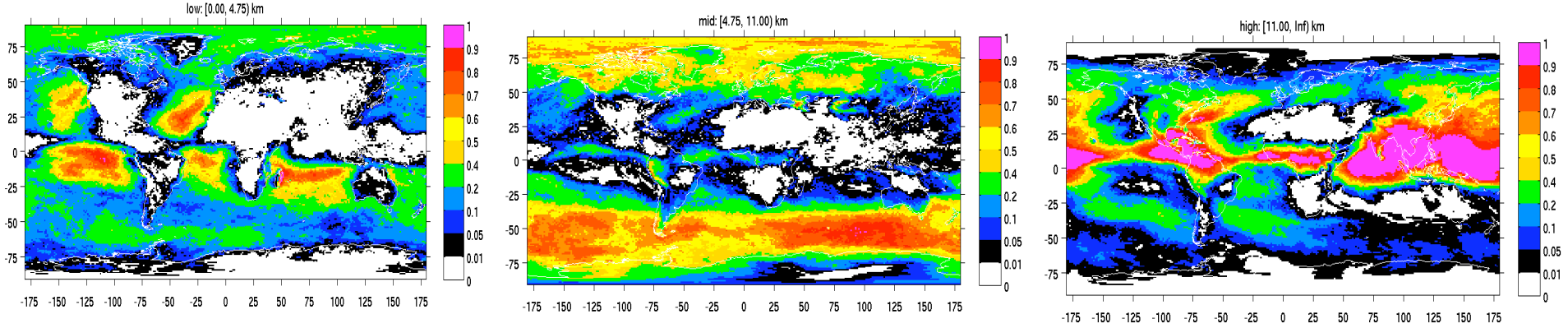
Cloudsat, ECMWF and GOES5



ECMWF

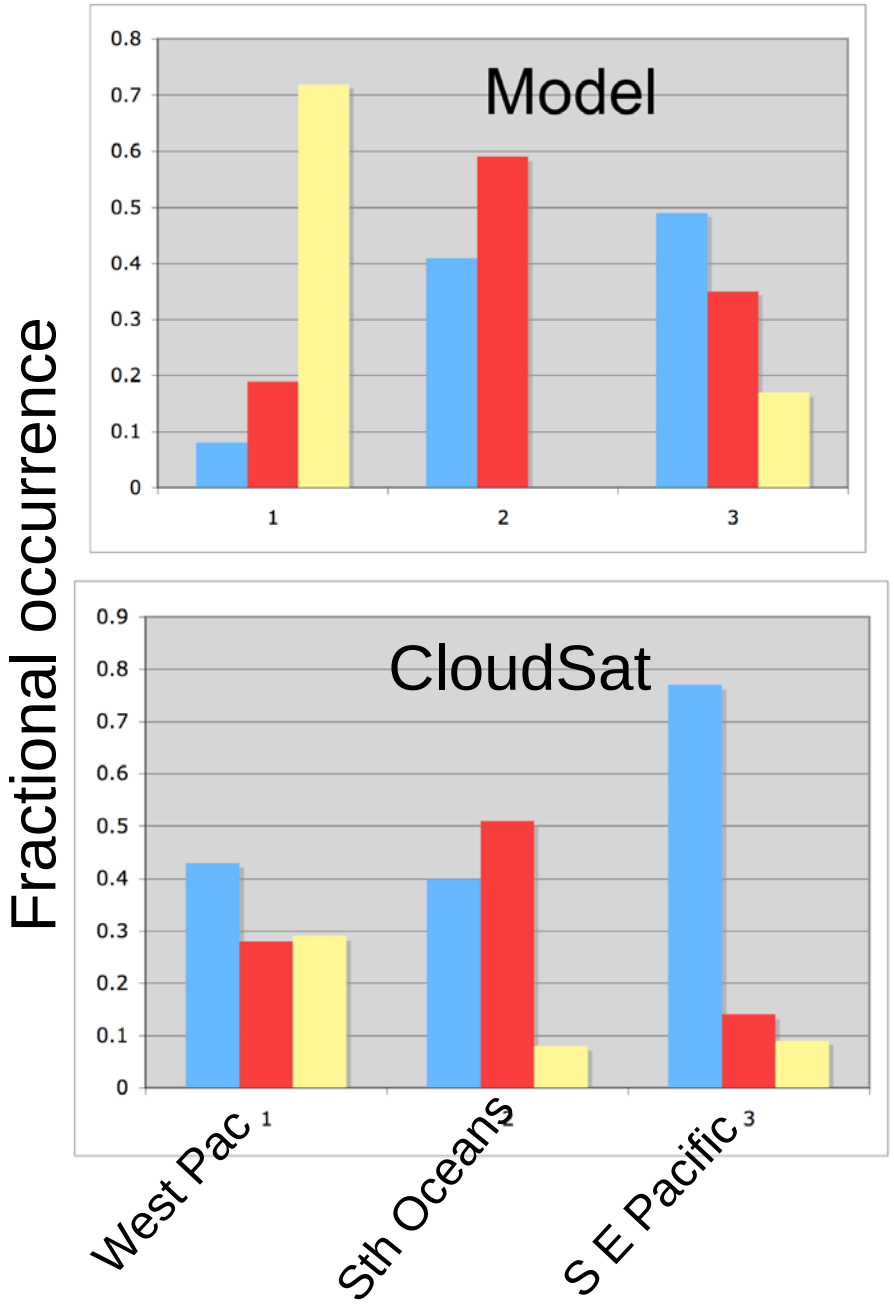


GOES5



preliminary

Precipitation Incidence
JJA, selected areas

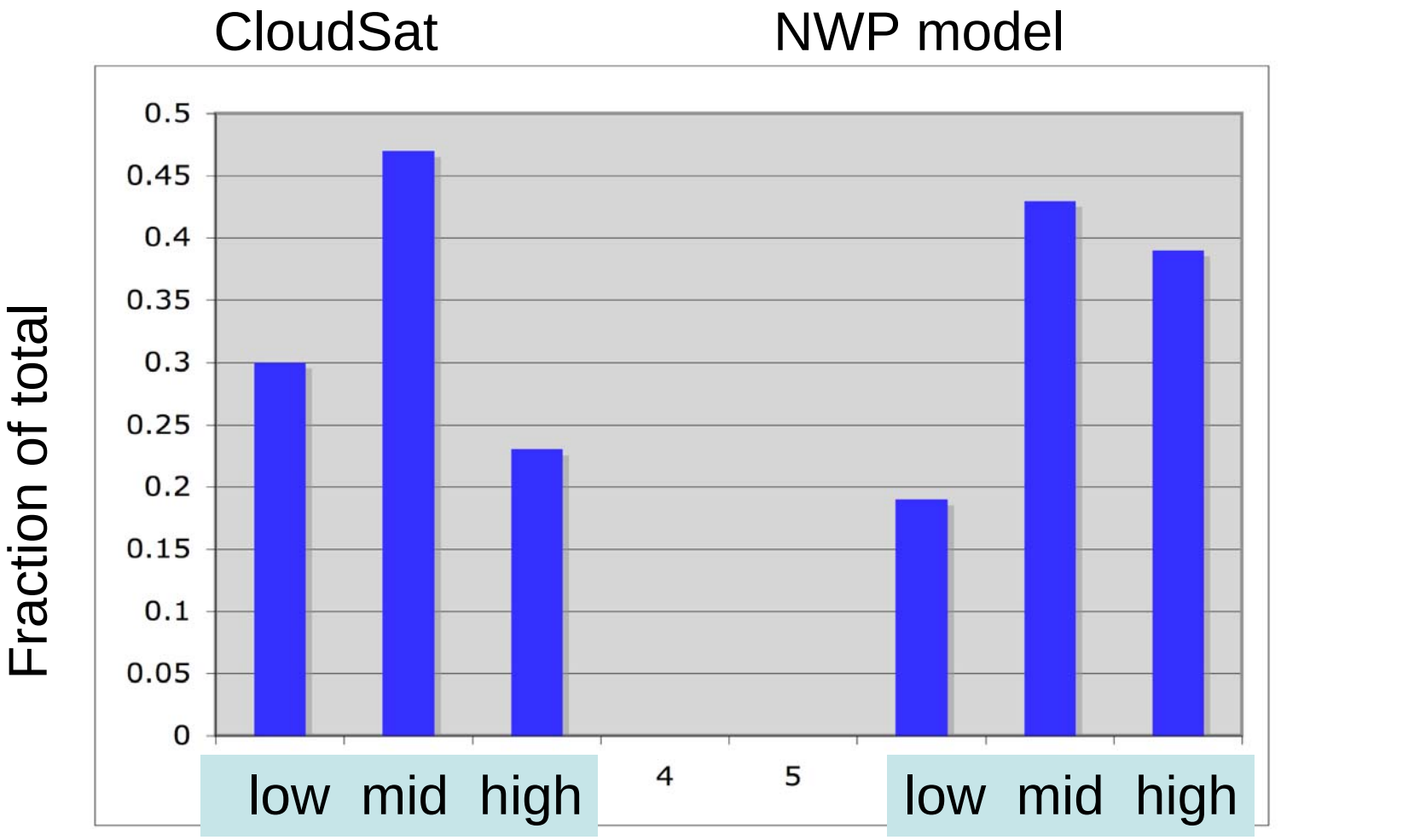


low

mid

high

Fractional Accumulation JJA 60S-60N

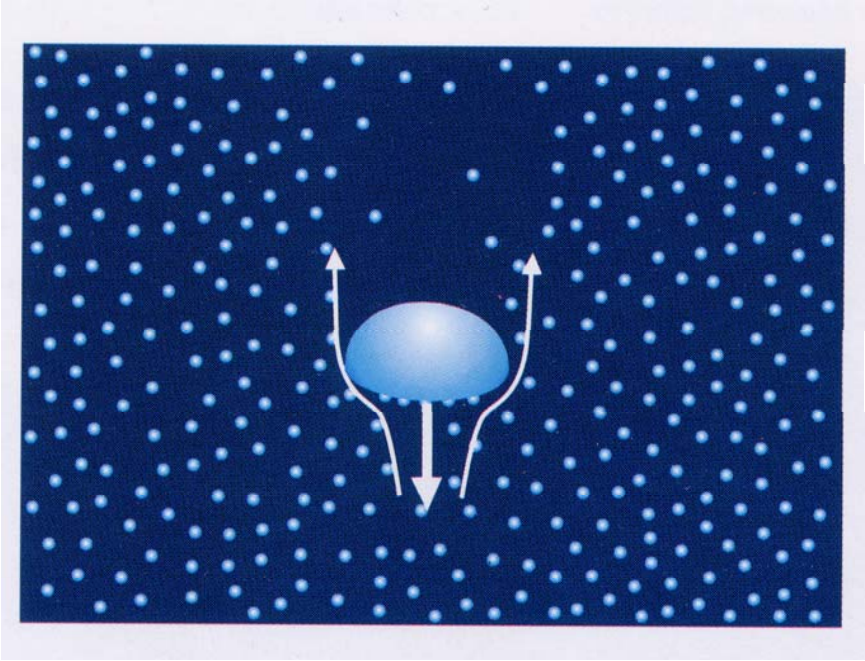


Preliminary

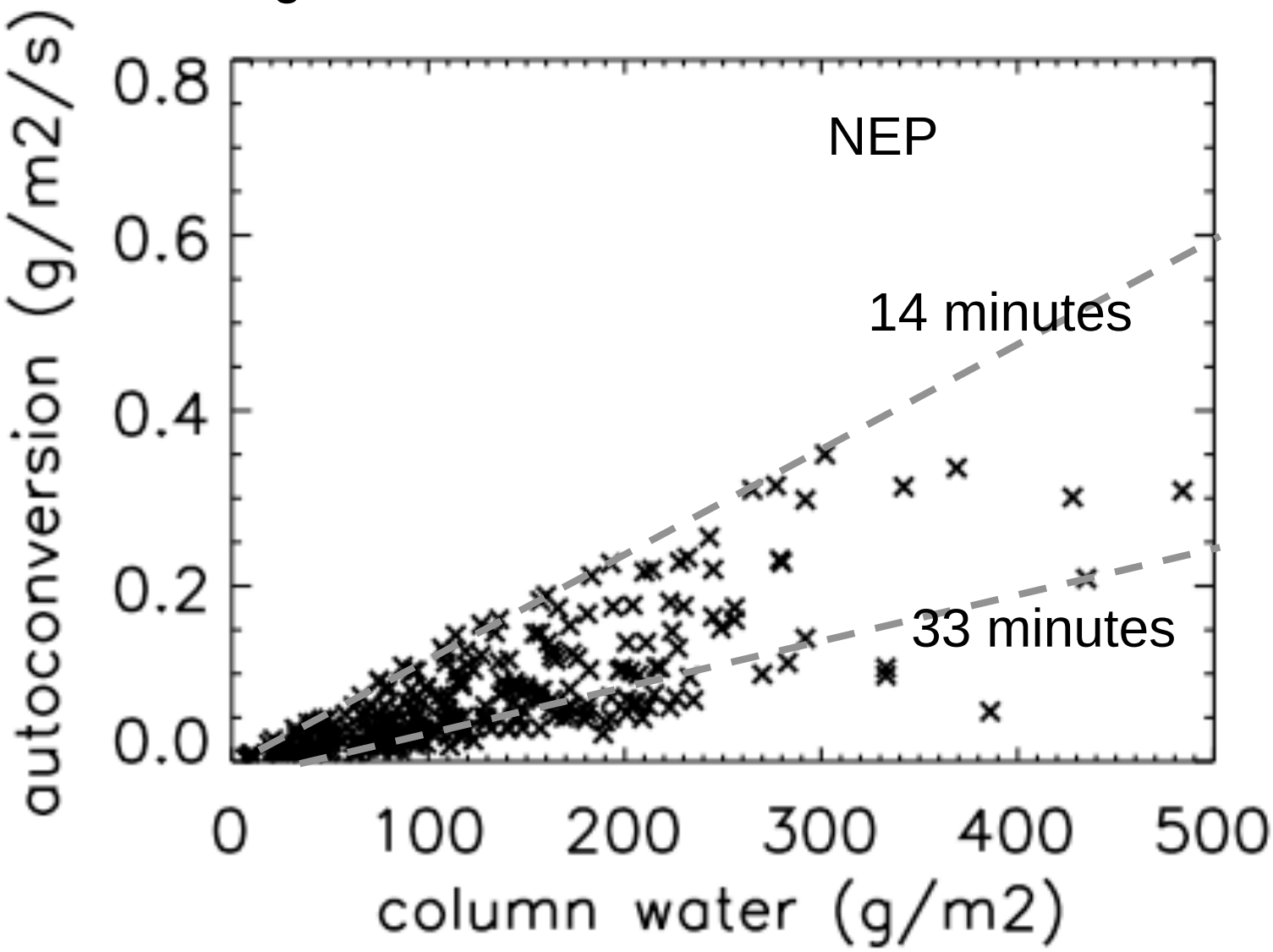
1. Studying the process of precipitation formation

The idea - estimate the rate at which cloud water is converted to rain and examine factors that influence this conversion process

Fundamental to most of the critical cloud/precipitation related problems that confront us (indirect effects, low cloud life cycle, large-scale precipitation, ….)

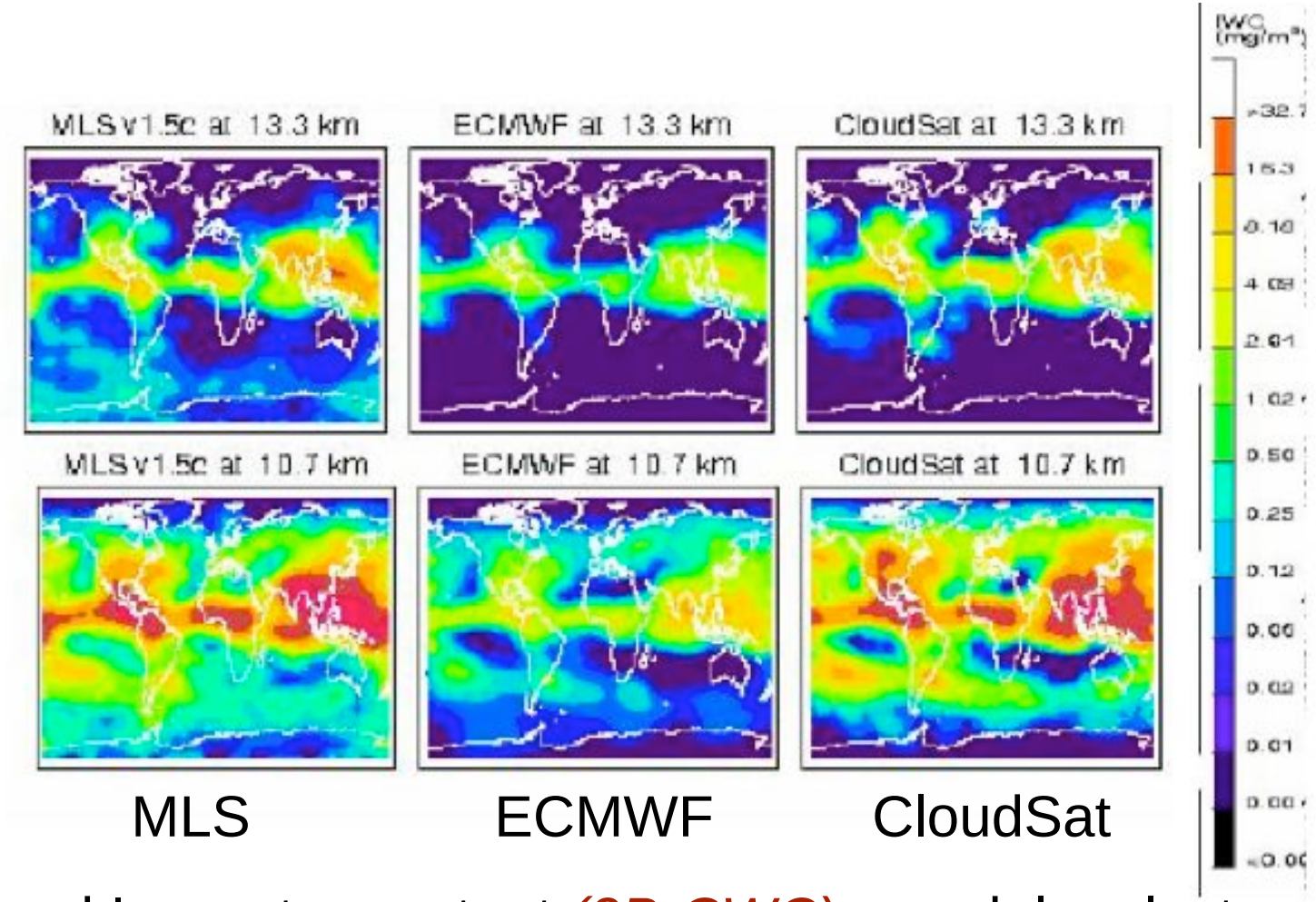


Using matched A-Train observations



Stephens and Haynes, 2007

2. Ice content and the study of UT moisture

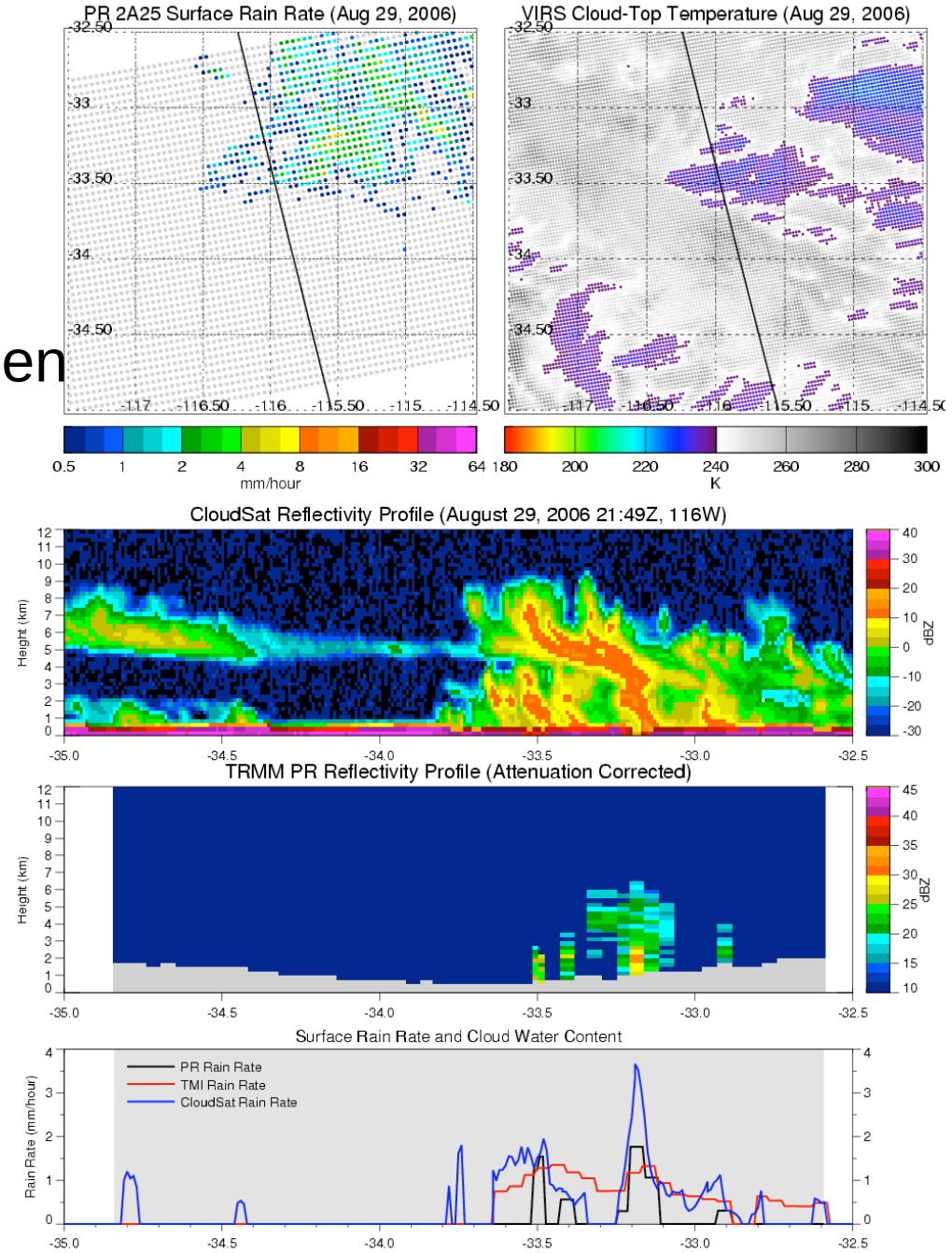


Cloud Ice water content *(2B-CWC)* - modelers last line of defense against measured TOA fluxes[1]

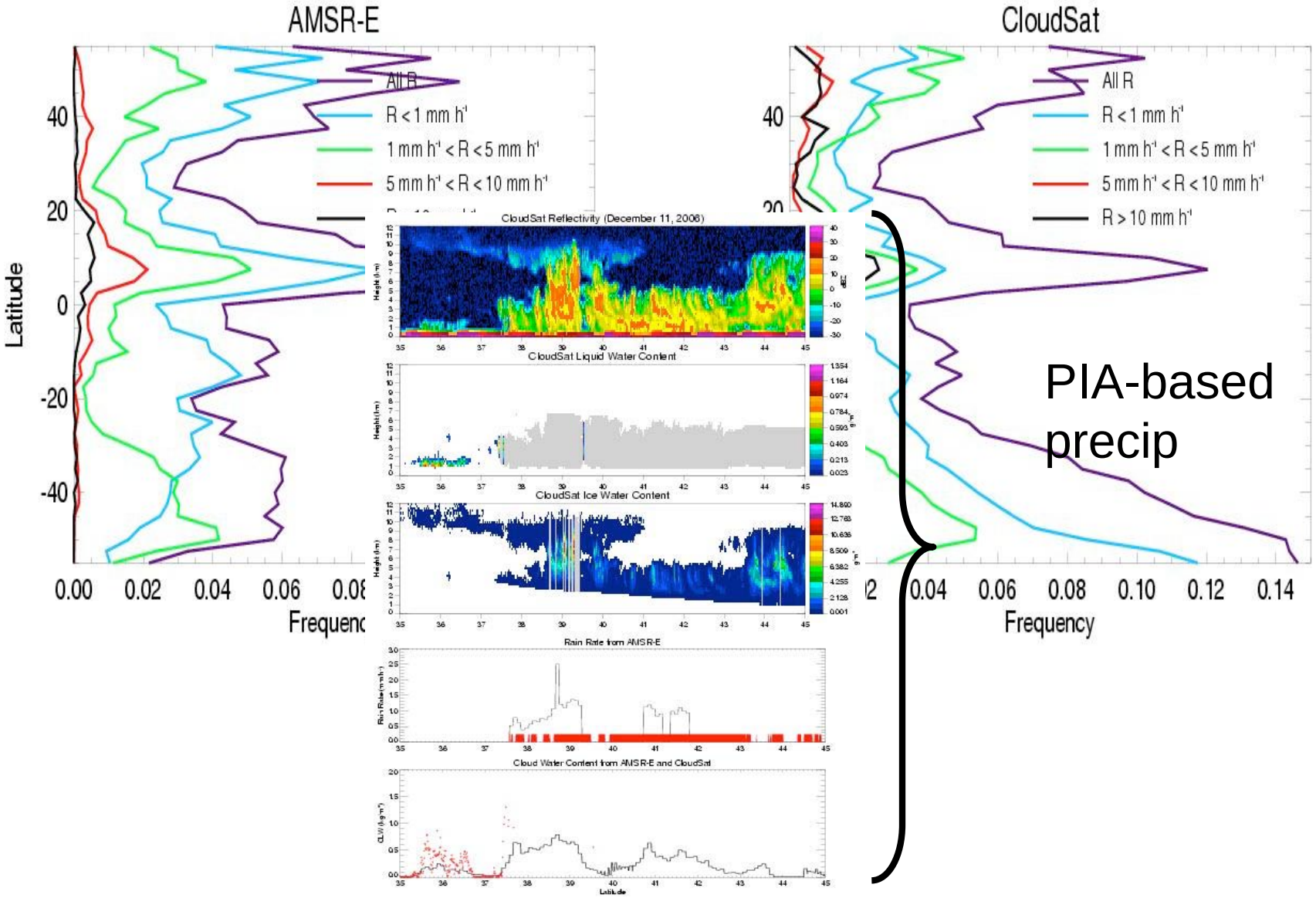
[1] Tony DelGenio

Toward quantifying Precipitation from CloudSat

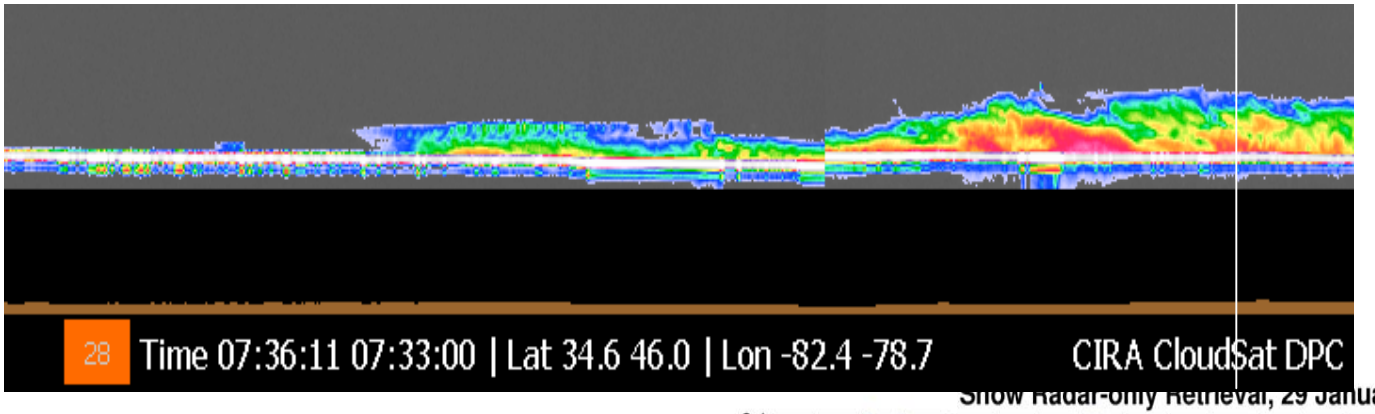
1. Comparison between CloudSat and TRMM



2. Comparison AMSR-E



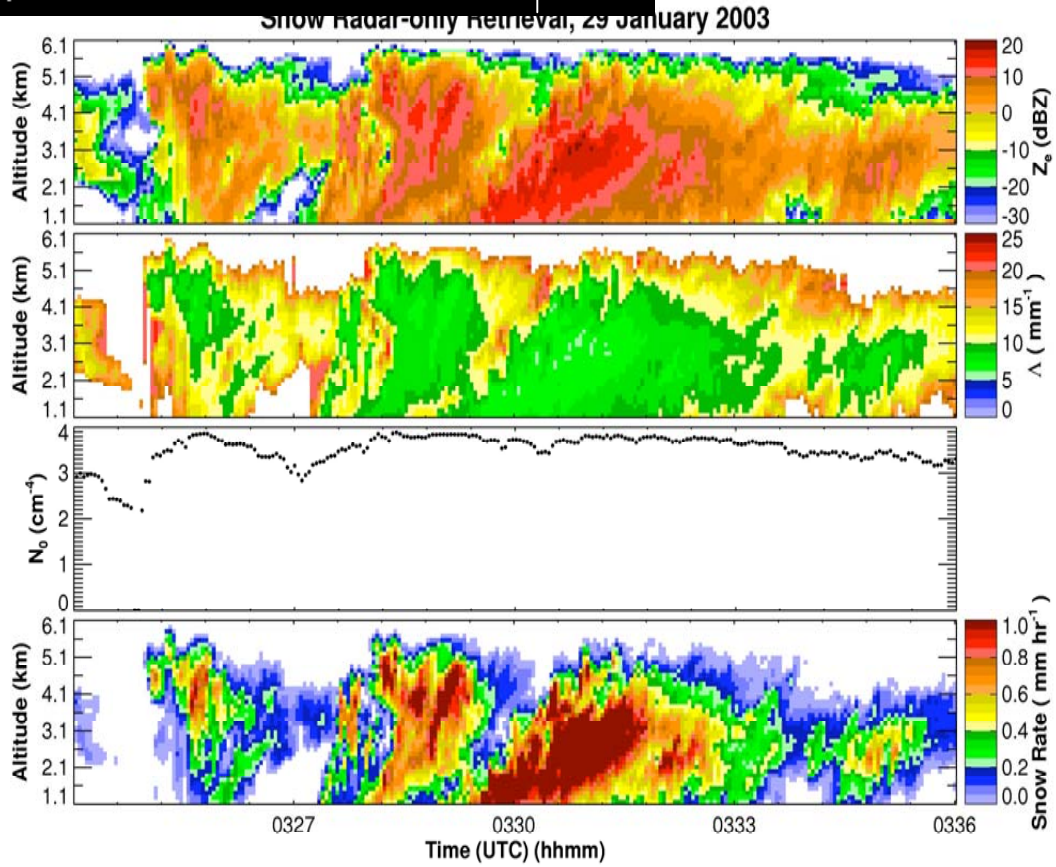
3. Quantifying of snowfall



CloudSat obs of snowfall over C3VP val site

The Canadian C3VP experiment CloudSat cloud and cloud precipitation validation

Example Cloudsat-like retrieval of snow



Summary

We are gathering new important insights (& understanding) on the global water cycle and the (atmospheric) moist processes that shape it - such as insights on

- global precipitation efficiency,
- cloud structures in relation to storm types and precipitation characteristics - we are finding substantially more light rain from shallow clouds than is observed with other sensors or modeled
- we are gaining insights on the warm-rain production
- influence of clouds on atmospheric and surface energetics and its connection to the water cycle

The knowledge being gathered offers a means for testing prediction models at much deeper levels than has been possible in the past. These results are already impacting moist physics formulations in global models.

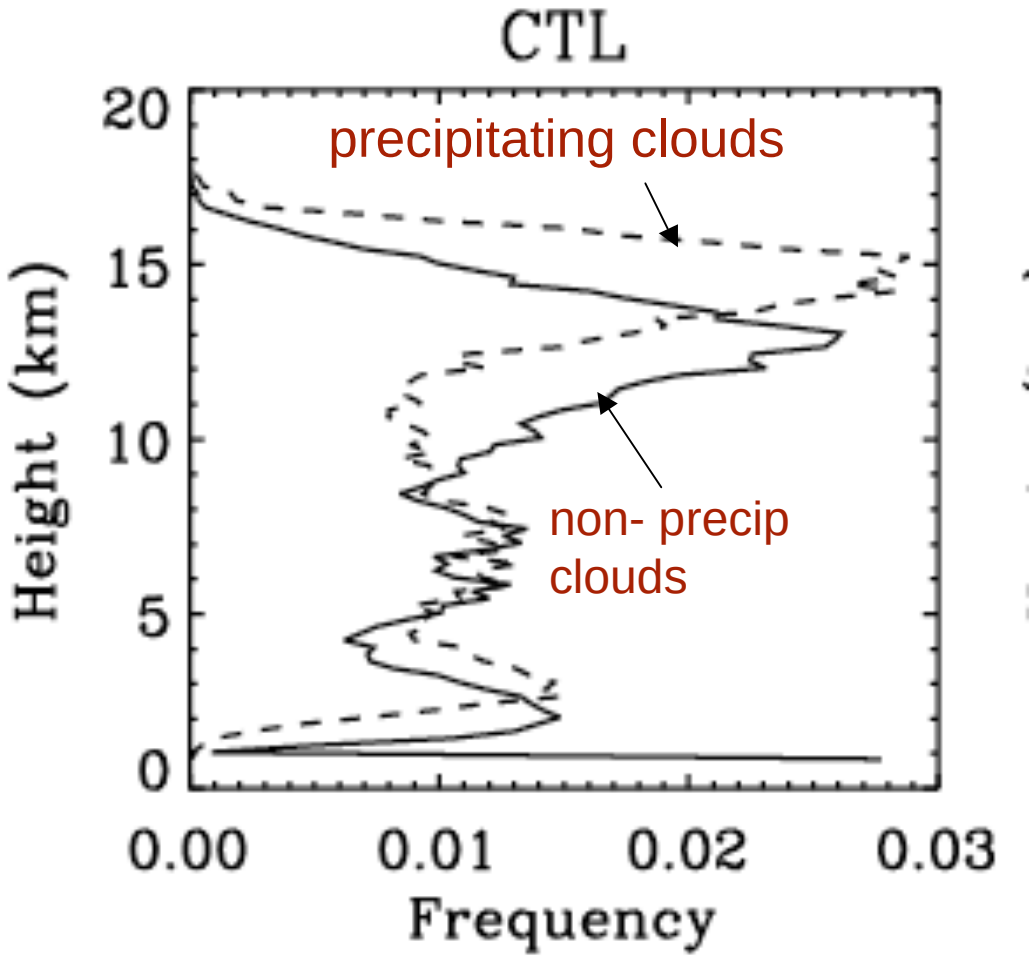
Composite vertical profile for west pac, JJA

Minimum cloud top heights distributions

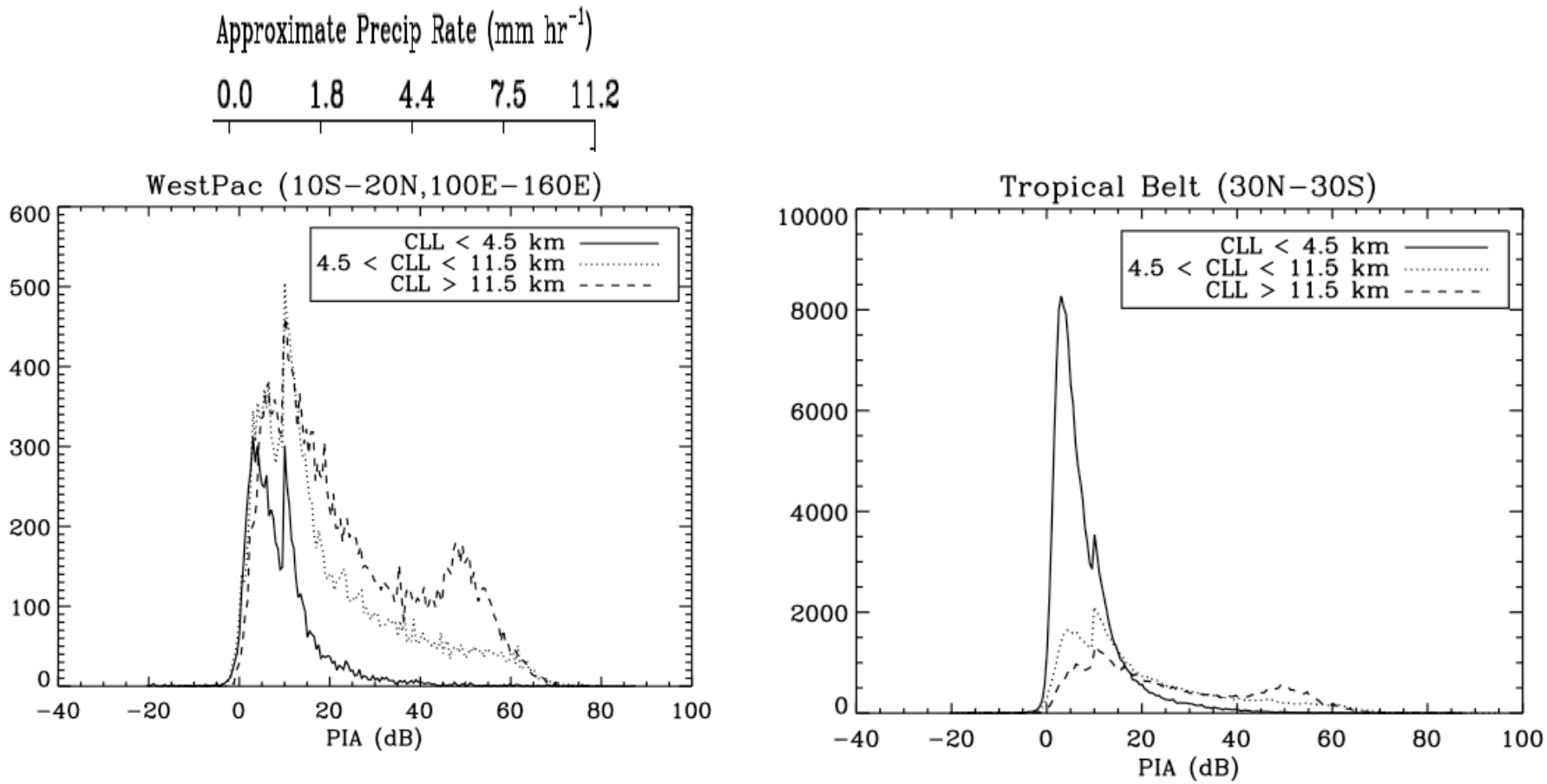
Of note:

•Trimodality (quadra-modal) heights

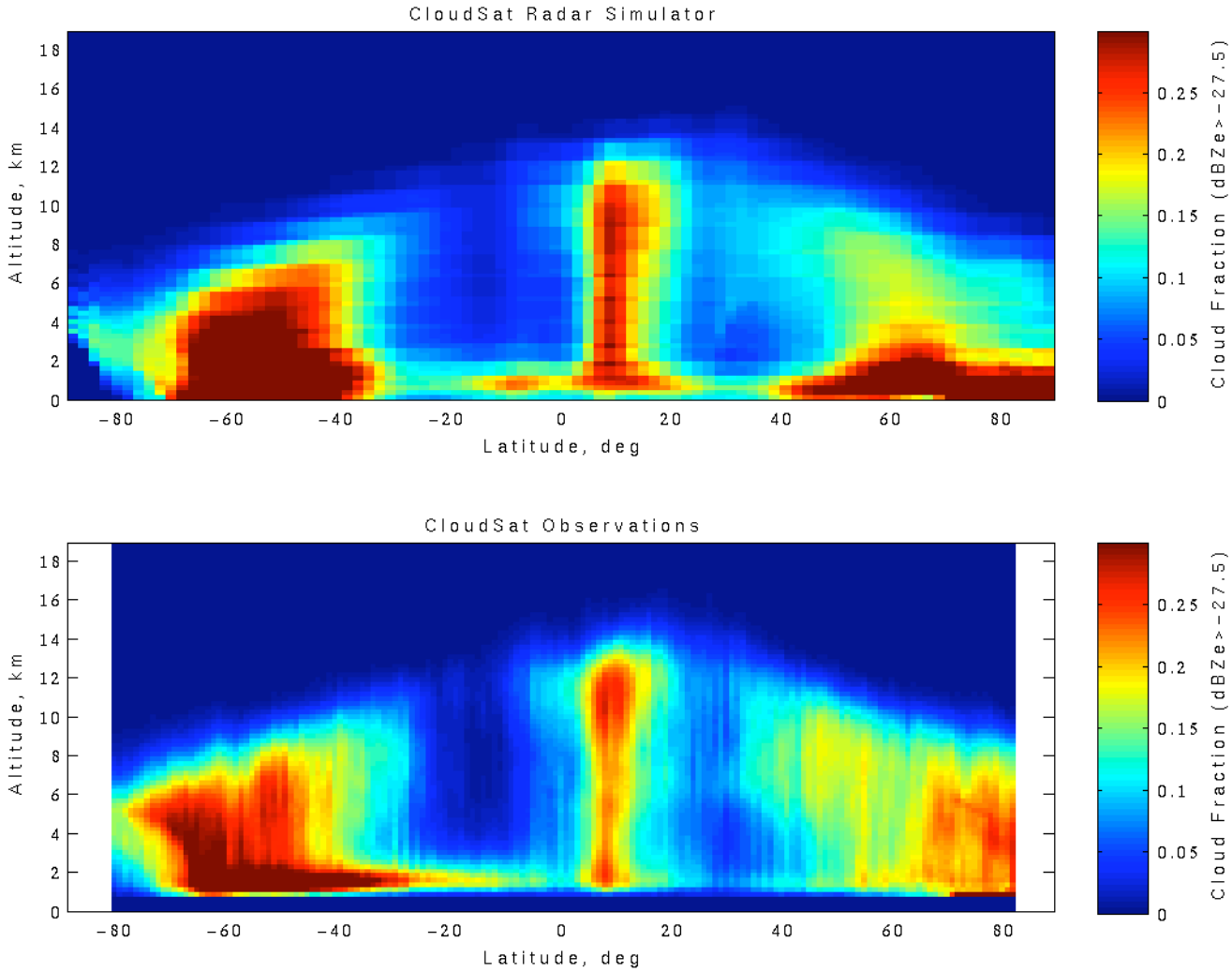
• precipitating clouds are deeper than non precipitating clouds



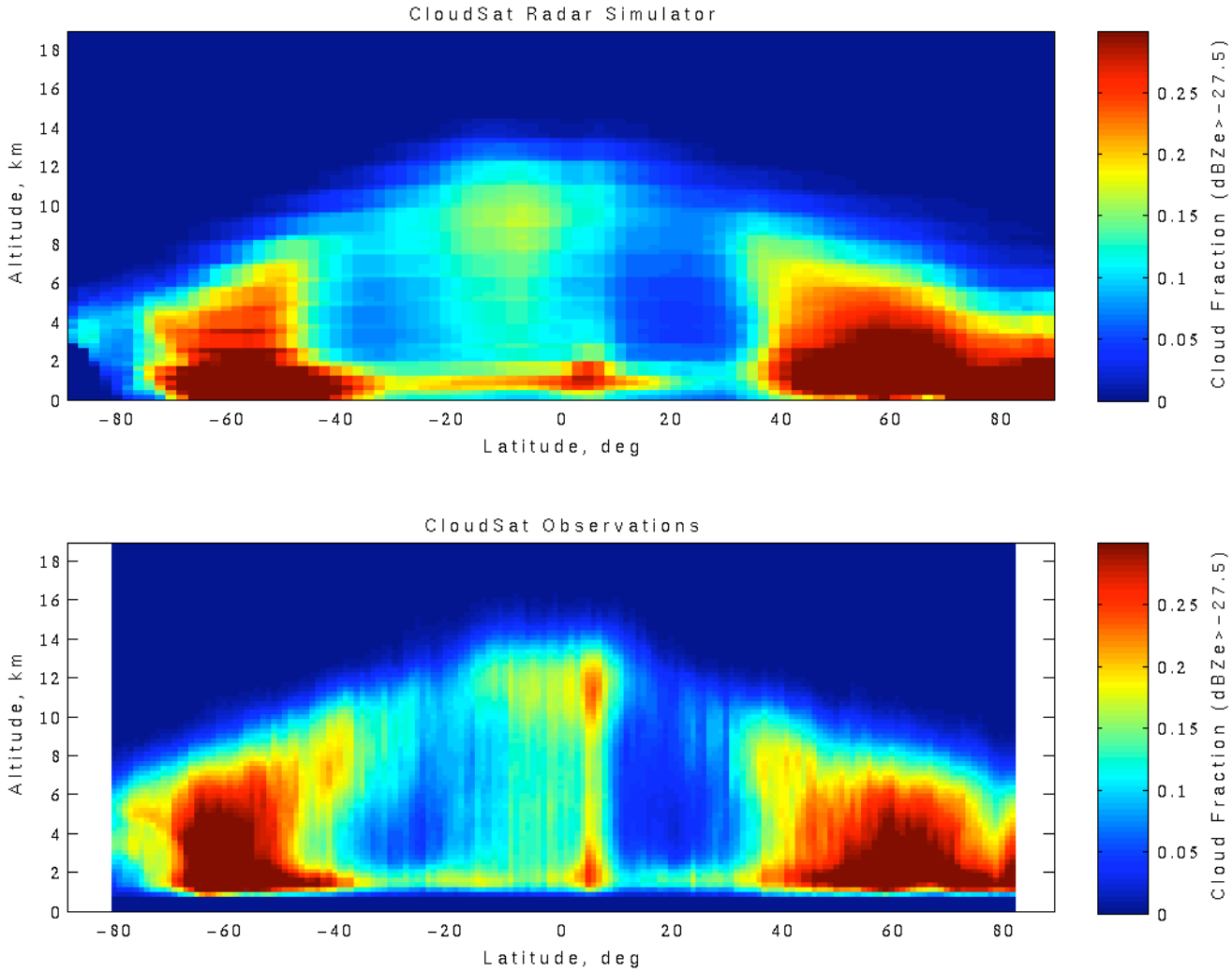
Revealing the bimodality of tropical precipitation



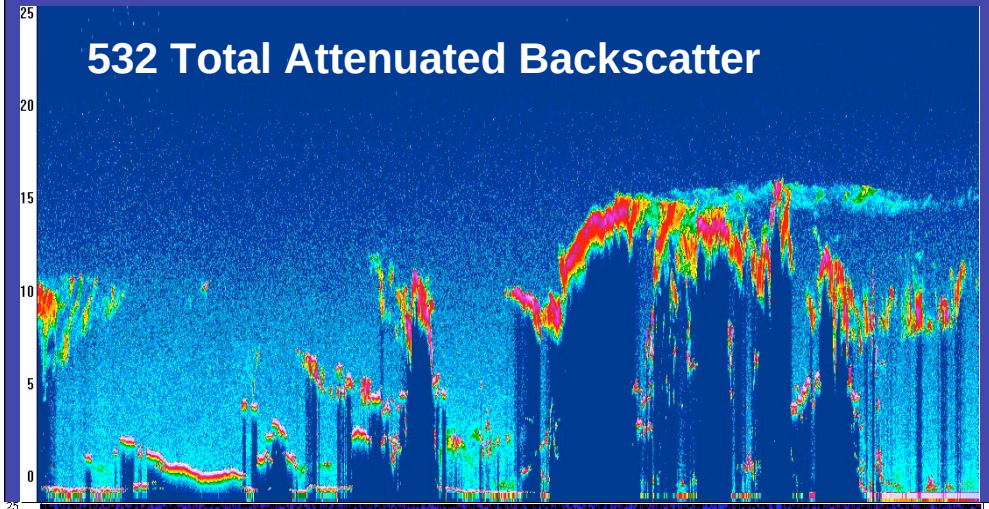
July

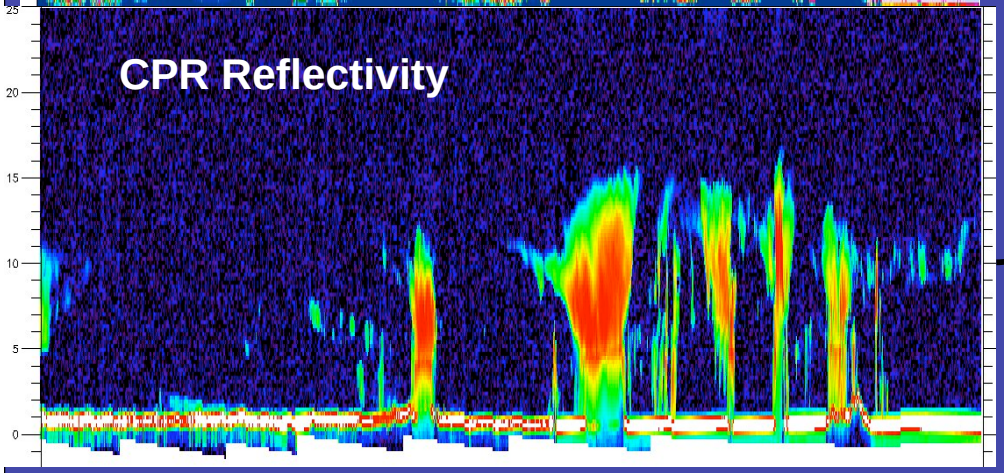

CloudSat Radar Simulator
Altitude, km
Latitude, deg
Cloud Fraction (dBZe>-27.5)
CloudSat Observations
Altitude, km
Latitude, deg
Cloud Fraction (dBZe>-27.5)

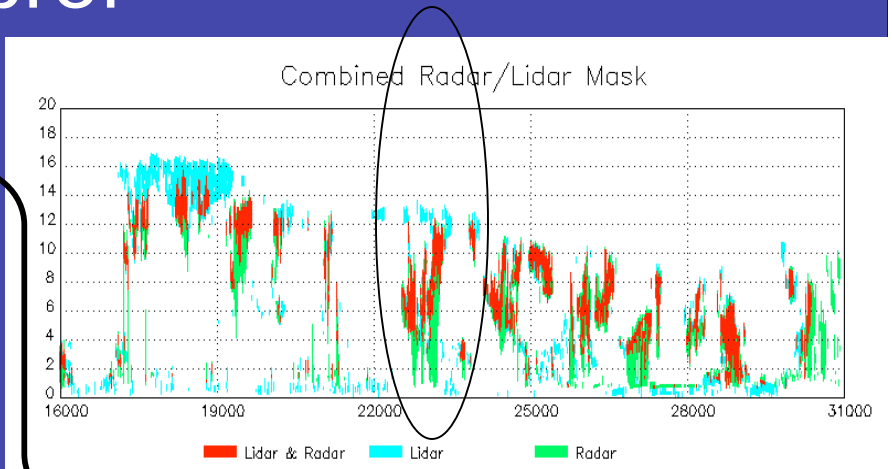
December

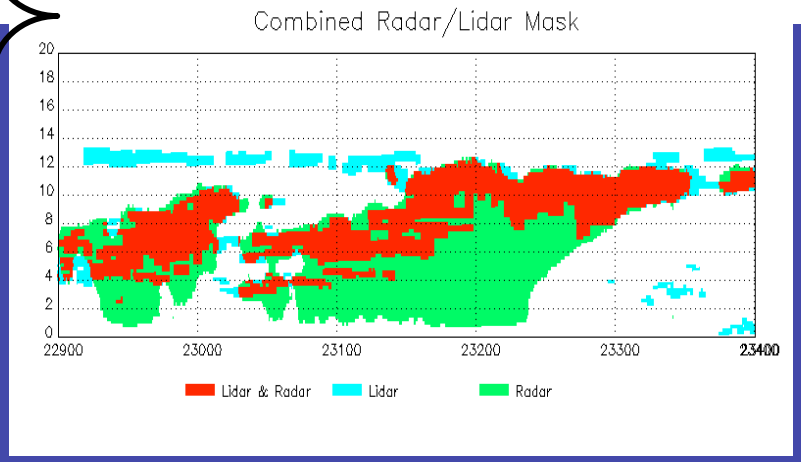

CloudSat Radar Simulator
Altitude, km
Latitude, deg
Cloud Fraction (dBZe>-27.5)
CloudSat Observations
Altitude, km
Latitude, deg
Cloud Fraction (dBZe>-27.5)

Preliminary steps toward the CloudSat radar/lidar geoprof



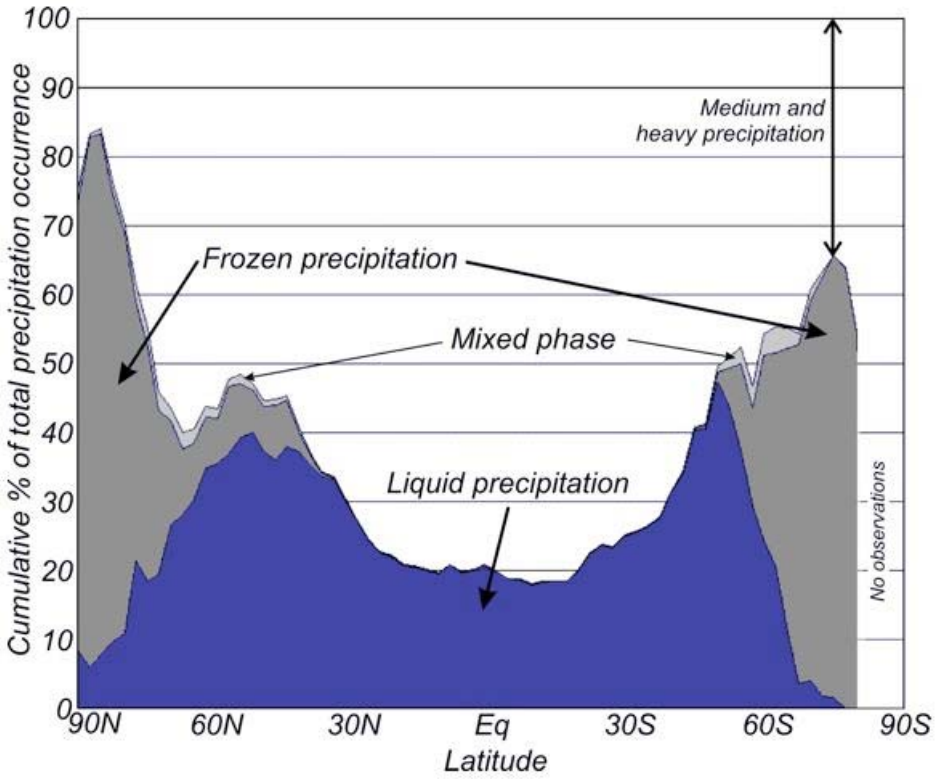




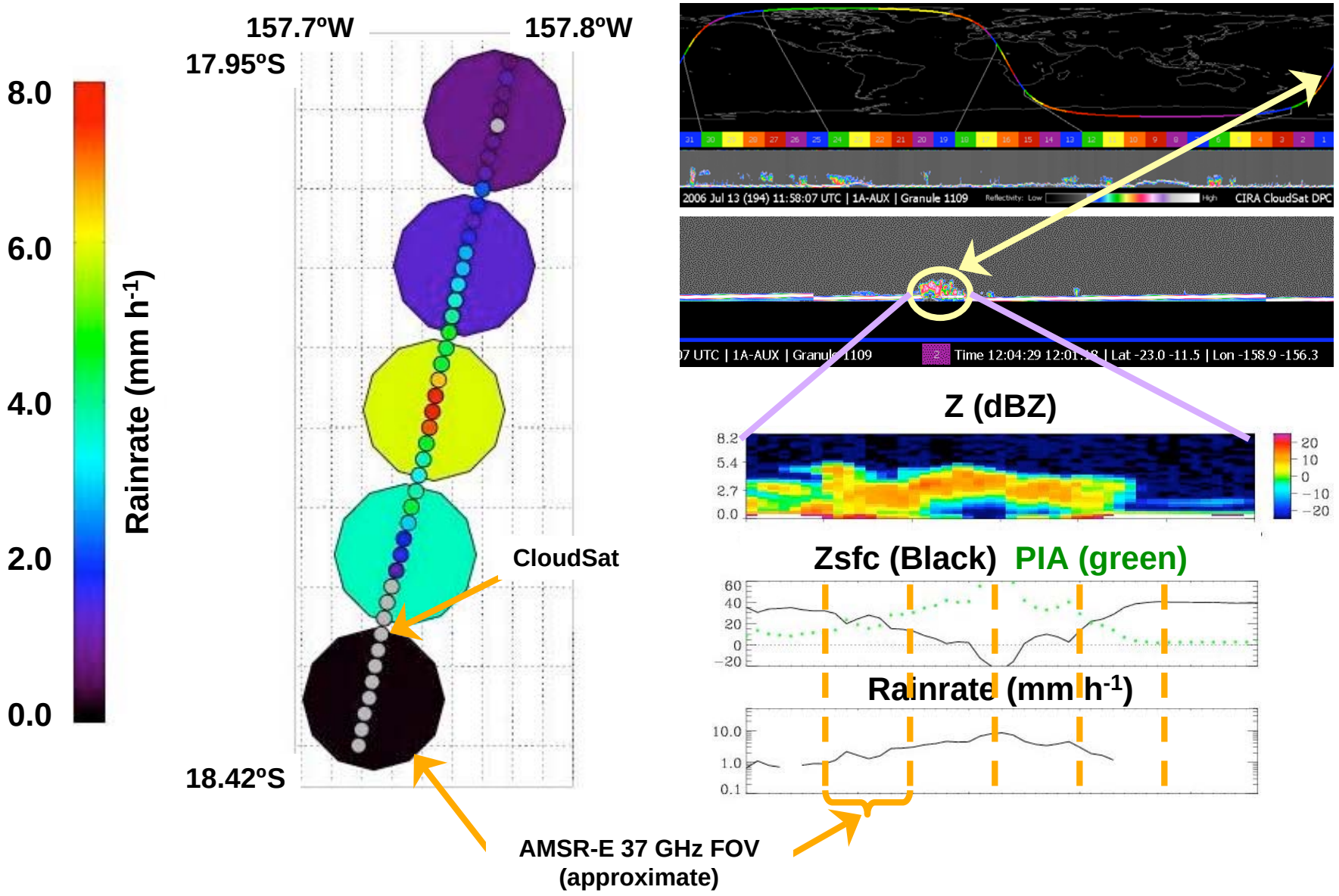


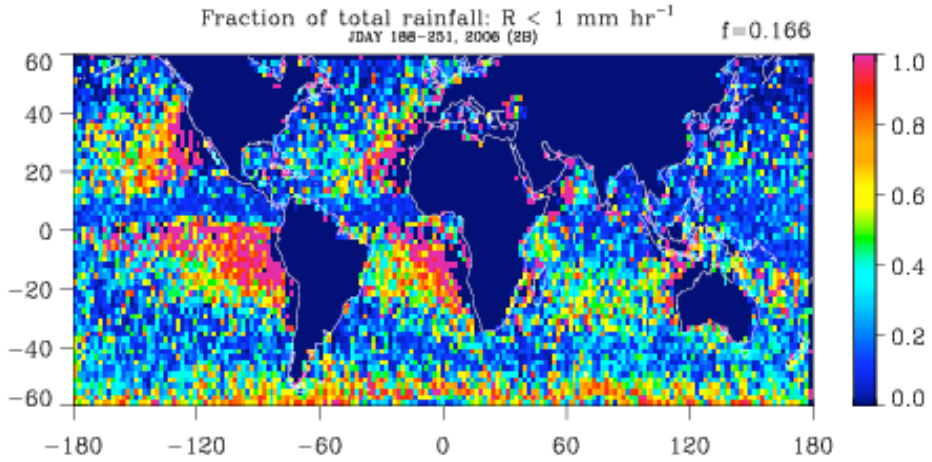
Preliminary example for portion of an orbit

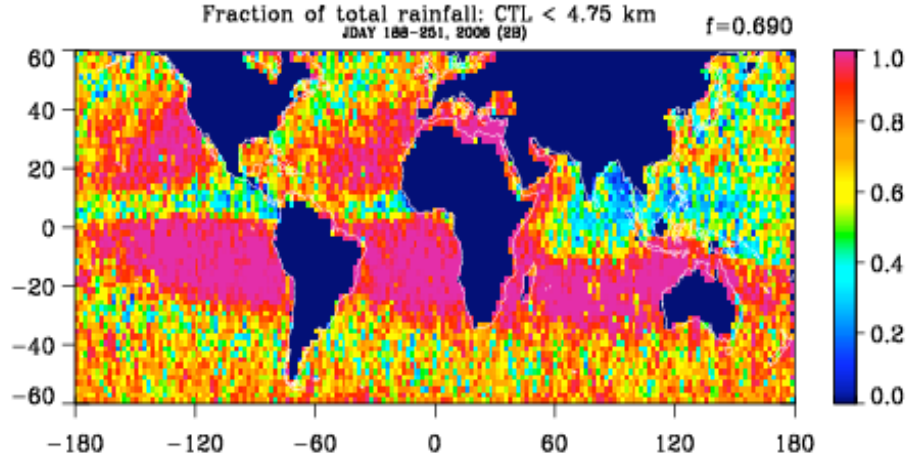
Courtesy Jay Mace

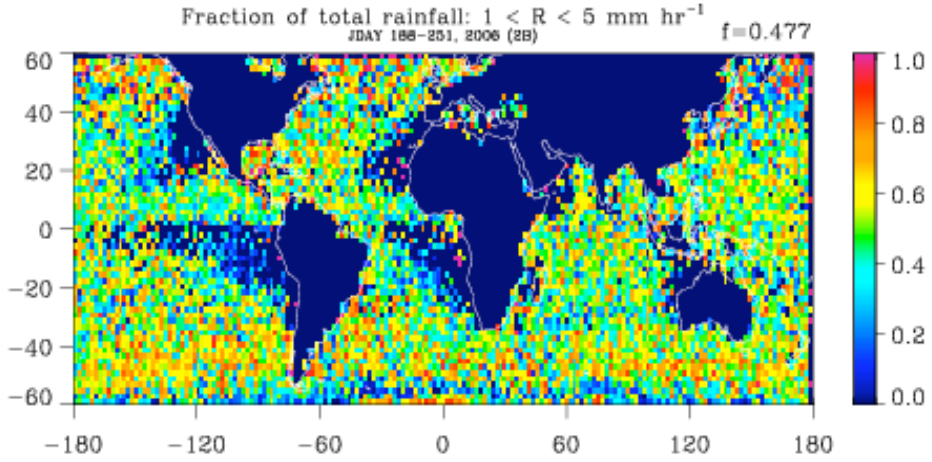

100
90
80
70
60
50
40
30
20
10
0
Cumulative % of total precipitation occurrence
Medium and
heavy precipitation
Frozen precipitation
Mixed phase
Liquid precipitation
No observations
90N
60N
30N
Eq
30S
60S
90S
Latitude

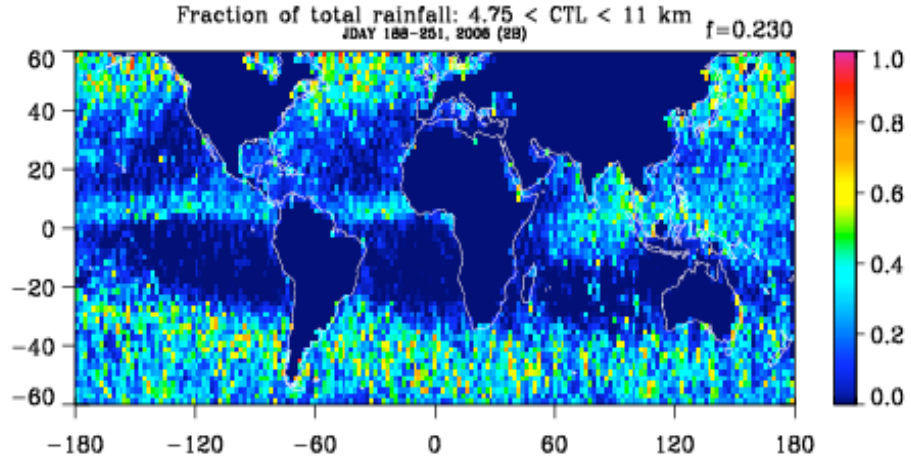
Pixel-Level Comparisons

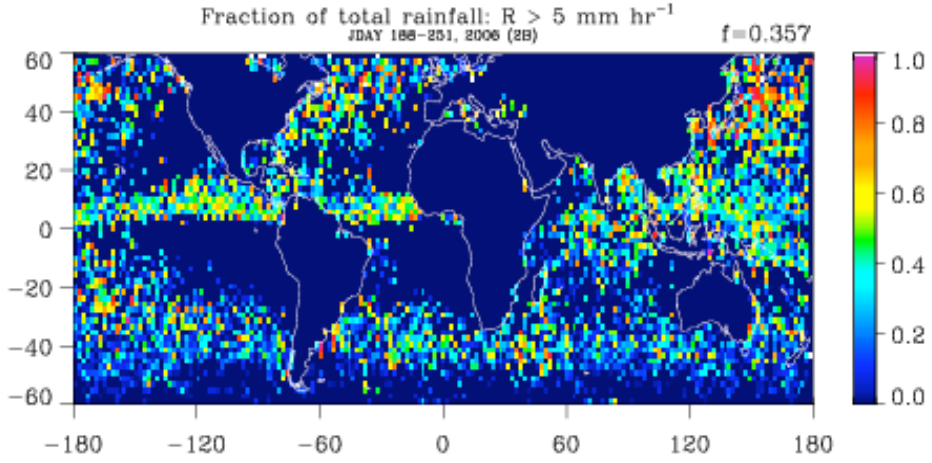


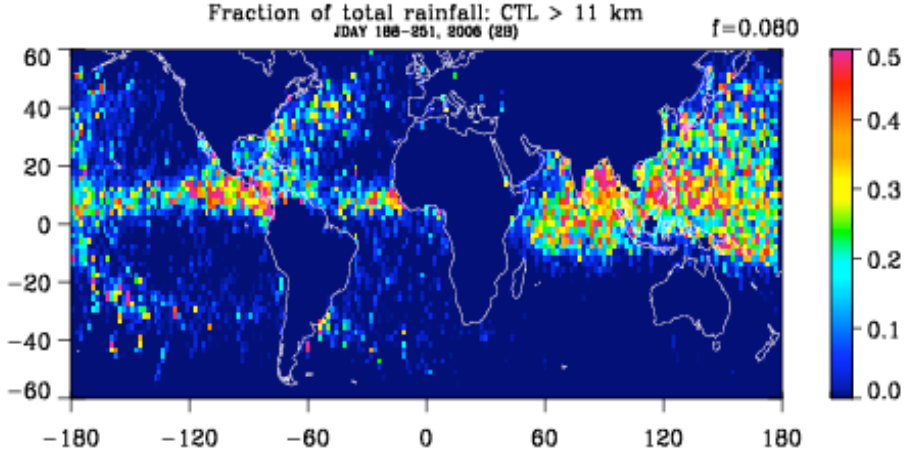

Fraction of total rainfall: R < 1 mm hr^{-1}
JDAY 188-251, 2006 (2B)
f=0.166


Fraction of total rainfall: CTL < 4.75 km
JDAY 188-251, 2006 (2B)
f=0.690

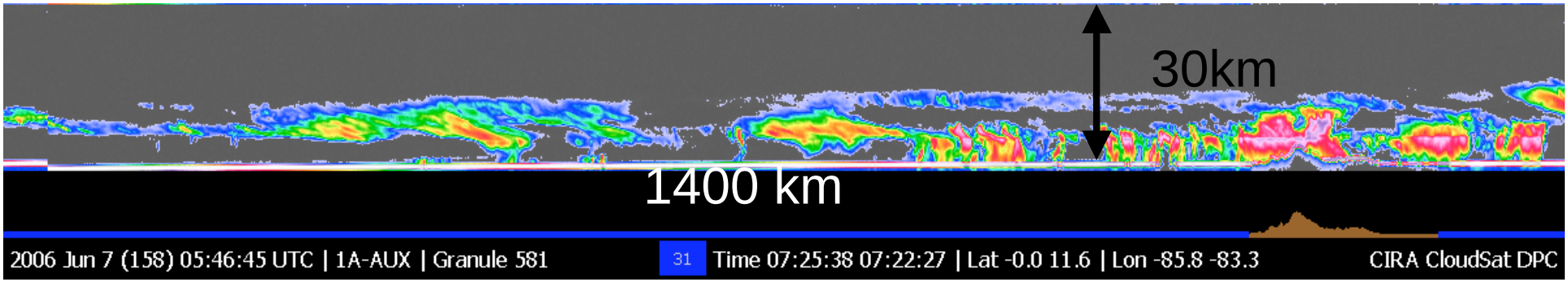

Fraction of total rainfall: 1 < R < 5 mm hr^{-1}
JDAY 188-251, 2006 (2B)
f=0.477


Fraction of total rainfall: 4.75 < CTL < 11 km
JDAY 188-251, 2006 (2B)
f=0.230

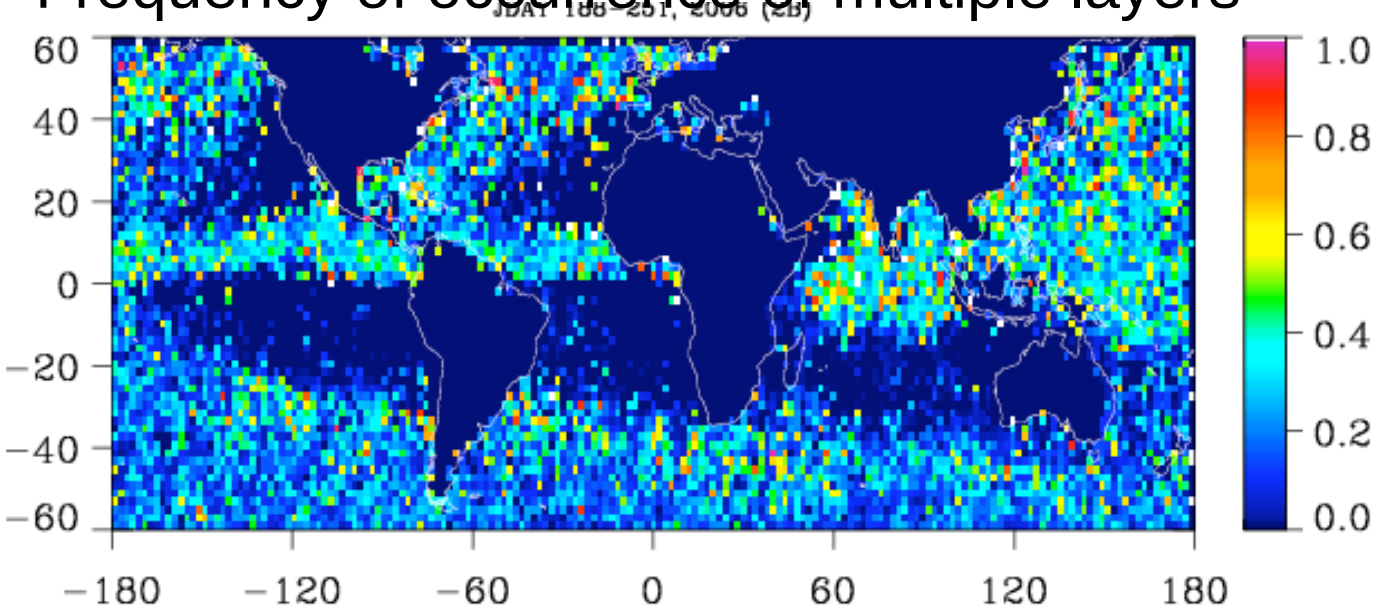

Fraction of total rainfall: R > 5 mm hr^{-1}
JDAY 188-251, 2006 (2B)
f=0.357


Fraction of total rainfall: CTL > 11 km
JDAY 188-251, 2006 (2B)
f=0.080

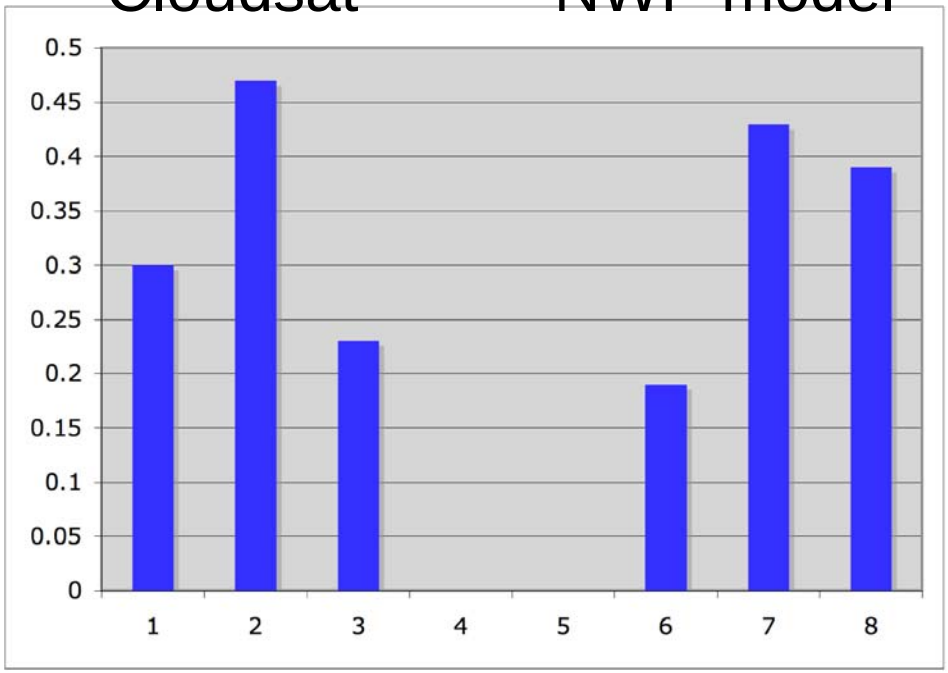
Our research using ARM observations at one tropical site reveals that tropical convective precipitation falling from multiple layered clouds is frequent and significant (~40% of total) - CloudSat also suggests it is a ubiquitous feature of tropical precipitating systems

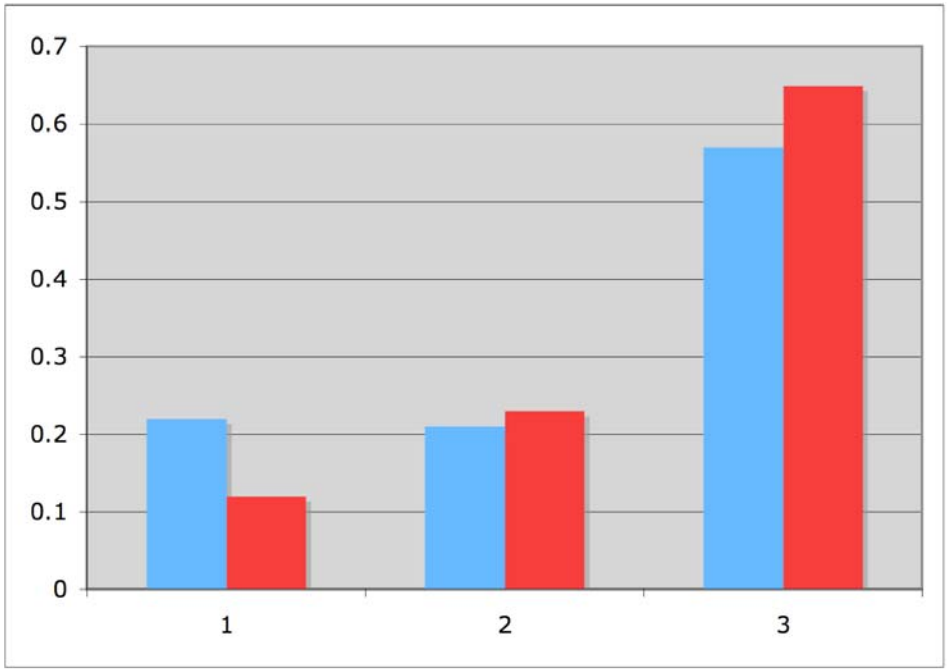


Frequency of occurrence of multiple layers



Cloudsat NWP model

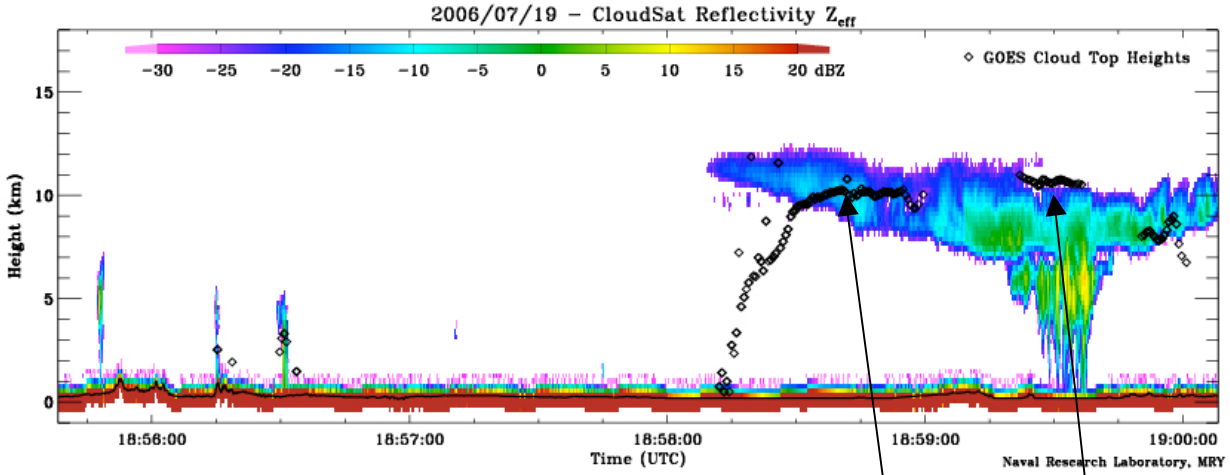




Fractional Accumulation

JJA 60S-60N

Cloud top comparisons - GOES IR



Poor agreement in thin, tenuous clouds

Good agreement over Thick clouds